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UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY
MINERALS MANAGEMENT SERVICE

Estimates of Undiscovered Conventional Oil and Gas Resources in the United States—A Part of the Nation's Energy Endowment

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U.S. GEOLOGICAL SURVEY

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MINERALS MANAGEMENT SERVICE

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A joint assessment of the undiscovered conventionally recoverable oil and natural gas resources of the United States

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

MINERALS MANAGEMENT SERVICE
Barry A. Williamson, Director

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FOREWORD

Two Agencies of the U.S. Department of the Interior, the U.S. Geological Survey (USGS) and the Minerals Management Service (MMS), recently completed this assessment of the undiscovered conventionally recoverable oil and natural gas resources of the United States.[1] It considers new geological, technological, and economic information and uses more definitive methods of resource appraisal than previous assessments. The assessment was conducted over a period of more than 2 years and reflects data and information available as of January 1, 1987.

Because oil and gas are so important to the U.S. economy, there is substantial interest in the resource base from which future oil and gas production will come. Many readers of this report will have a strong interest in determining how much oil and gas is likely to be produced in the next several years from resources yet to be discovered. Important issues of public policy and private investment hinge on expectations about the extent to which the United States will be able to meet its energy demands from domestic resources during the next two or three decades.

Geologists and managers who want to assess the relative potential for future discoveries in various parts of the country will find this report helpful because the regional estimates were developed by using common methods and assumptions. Although the estimates in this report are good indicators of the relative oil and gas potential of various parts of the United States outside of known fields, they provide only limited information about future oil and gas production. The reasons for this limitation will become apparent as the scope, methods, and assumptions of the assessment are presented.

Scope of the Assessment

This assessment covers only a comparatively small portion of all the oil and gas resources believed to exist in the United States. Known domestic fields contain *reserves*—resources that are economic to produce by conventional methods at current prices and costs—of about 30 billion barrels of oil (BBO) and 206 trillion cubic feet (TCF) of gas. This report provides estimates of *undiscovered conventionally recoverable* oil and gas resources located *outside of known oil and gas fields*. In this assessment, *known* means confirmed by exploratory drilling; *conventionally recoverable* means producible by natural pressure, pumping, or injection of water or gas. Estimates are presented in two categories:

- *undiscovered recoverable resources*—accumulations of sufficient size and quality that could be produced with conventional recovery technologies without regard to commercial economic viability.
- *undiscovered economically recoverable resources*—that part of the undiscovered recoverable resource that is economically recoverable (that is, commercially profitable) by current conventional technologies and with specified economic assumptions.

This assessment covers only one of several categories of domestic oil and gas resources. Other resources—involving substantial amounts of recoverable or potentially recoverable oil and gas—are *not* included in this assessment and include:

- oil and gas yet to be recovered from known oil and gas fields by either conventional or enhanced oil recovery (EOR) methods.
- oil and gas yet to be recovered by EOR from undiscovered conventional resources, even though the enhanced recovery is done by conventional technologies and may be economic.
- resources in so-called *unconventional* sources of oil and gas, including tar deposits, intractable heavy oil deposits, oil shales, gas in low-permeability "tight" reservoirs, coalbed methane, gas in geopressurized shales and brines, natural gas hydrates (clathrates), and oil and gas synthesized from organic sources, such as coal.

Unconventional oil and gas resources have not yet made a major contribution to production and present rather specialized issues for geologists searching for additional oil and gas fields. However, technological advances and changing economic conditions may make them important sources of oil and gas production in future decades.

Methodologies Used in This Assessment

The methodologies employed are based on a probabilistic, geologic play-oriented approach, although some variances were used when data, information, or other factors precluded strict adherence to that approach. A geologic play is a group of geologically related prospects having similar hydrocarbon sources, reservoirs, and traps. Geologic play analysis requires either the estimation of the number and sizes of potential fields in an exploration play or the summation of individual prospect assessments in the play, depending upon the quantity of data available. Previous USGS assessments employed a *volumetric* approach to resource estimation. The methodologies employed by the USGS and MMS in this assessment are more advanced and data intensive.

The computational methods incorporate a systematic treatment of the probabilities that the events necessary to create and trap hydrocarbons have occurred in each play. There is no way short of exploratory drilling to replace such probabilities with certainty. In recognition of the uncertainties associated with estimating undiscovered accumulations of oil and natural gas, the estimates are presented as a range of possible occurrences: a *low* case having a 95-percent probability of that amount or more occurring, a *high* case having a 5-percent probability of that amount or more occurring, and a *mean* case representing the arithmetic average of all possible outcomes.

Several professional organizations conducted rigorous peer reviews of the data, methodologies, and assumptions used in this assessment. The Association of American State Geologists (AASG), at the request of our Agencies, examined the adequacy of the geologic information used in developing the assessment. A national meeting and several regional meetings were held with representatives of Federal and State Agencies, industry, and academia to review the data. The American Petroleum Institute and the Energy Information Administration (U.S. Department of Energy) attended the AASG meetings and concurrently conducted independent reviews. We have reviewed the comments and recommendations of these groups, and we are confident that the methodologies and data employed in this assessment are geologically and technically sound and the estimates

[1] This assessment updates earlier USGS estimates for the total United States reported in 1981 in Circular 860, *Estimates of Undiscovered Recoverable Conventional Resources of Oil and Gas in the United States*, and MMS estimates for the Federal Outer Continental Shelf reported in 1985 in OCS Report MMS 85-0012, *Estimates of Undiscovered Economically Recoverable Oil and Gas Resources for the Outer Continental Shelf as of July 1984*.

reasonable.[2] We also have requested the National Academy of Sciences (NAS) to examine the methodologies and to review our entire oil and gas resource assessment process. A final report of the NAS review is scheduled for mid-1990.

A Department of Energy report on the natural gas resource base of the United States[3] compared assessments made by USGS/MMS and the Potential Gas Committee by considering geologically comparable estimates for specific regions. When assessments of similar resource categories were compared, the estimates of the Department of the Interior and the Potential Gas Committee were very close.

Key Economic Assumptions

Although this study is primarily a geological study, certain economic assumptions were made to facilitate the assessment. Estimates of undiscovered *economically recoverable* resources were based on the assumption that exploratory drilling of each play or prospect had been completed and that the decision whether the resulting discovery was economically recoverable was made on January 1, 1987. This decision was assumed to be based on development and production costs and oil and gas price expectations as of that date.

The assessment also produced estimates based on the assumption that conventional recovery would take place wherever technologically possible even if the resulting oil and gas production would not be commercially profitable. These estimates are called *recoverable* resources as compared to *economically recoverable* resources. Estimates of recoverable resources show the greater amounts of oil and gas that may be found and produced as technological advances reduce the costs of conventional recovery or as higher oil and gas prices make recovery of higher cost resources profitable.

Readers interested primarily in future oil and gas production should be aware of the limitations created by these economic assumptions. The timing of production from future discoveries depends upon:

- the existence of hydrocarbons in the new areas.
- the timing of the discoveries themselves.
- the technological and economic conditions in the years following discovery when decisions to invest in their development are made.

Moreover, the rate of production from each new discovery depends upon the amount of the resource and the characteristics of the reservoir. The estimates presented in this report are not intended to show either the timing of discovery or the rate of production that could occur. Furthermore, there is little relationship between the level of production from current U.S. reserves and the rate at which the remaining undiscovered resources will be produced.

Estimates of Undiscovered Conventional Oil and Gas Resources—January 1, 1987

Undiscovered *recoverable* conventional resources of oil in the United States, as of January 1, 1987, are estimated to range from about 33 to 70 BBO, with a mean estimate of 49 billion barrels (BB). Estimates of the gas resource range from about 307 to 507 TCF, with a mean estimate of 399 TCF (table 1).

Estimates of undiscovered *economically recoverable* oil and gas resources for the United States, as of January 1, 1987, are estimated to range from about 21 to 54 BBO and from 208 to 326 TCF of gas. The estimated mean value for oil is about 35 billion barrels and for gas about 263 TCF.

Table 1. Estimated mean value and range of probable values for each commodity category

Commodity	Mean Estimate	(*Range*)
Undiscovered recoverable conventional resources:		
Oil	49.4 BB	(*33.2–69.9*)
Gas	399.1 TCF	(*306.8–507.2*)
Natural gas liquids	8.6 BB	(*6.1–11.5*)
Undiscovered economically recoverable conventional resources:		
Oil	34.8 BB	(*20.7–53.8*)
Gas	262.7 TCF	(*208.2–325.5*)
Natural gas liquids	6.3 BB	(*4.6–8.4*)

These estimates of undiscovered conventional oil and gas resources are significantly lower than those published in earlier assessments (table 2). Much of the overall decline in estimated oil and gas resources results from massive exploration efforts by industry from 1980 to 1986. This drilling produced new discoveries of about 7 BBO and 65 TCF of gas, which directly reduced the amount of oil and gas remaining in the undiscovered category. More significantly, expected major discoveries in the frontier exploration areas of Alaska and the Atlantic OCS and in the overthrust belt of the Western United States were not forthcoming. These results have made geologists less optimistic about the oil and gas potential in those and other domestic areas than they were in 1981. The estimates of *economically recoverable* oil and gas resources were substantially lessened by the relatively low price assumptions that were used. Changes in the estimates also arise from the different assumptions, methods, and data that were used in the two studies.

Table 2. Comparison of earlier resource estimates with the current assessment

			USGS/MMS 1988 Recoverable	
	USGS 1975	USGS 1981	Tech.	Econ.
Oil (BB)	82	83	49	35
Gas (TCF)	484	594	399	263
NGL (BB)	16	18	9	6

[2] Examination or review by these organizations should not necessarily be interpreted as agreement with the results.

[3] *An Assessment of the Natural Gas Resource Base of the United States*, U.S. Department of Energy, DOE/W/31109–H1, May 1989.

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SUMMARY

In 1987, the U.S. Geological Survey and the Minerals Management Service completed a new assessment of the *undiscovered* conventional resources of crude oil and natural gas in the United States. This assessment responded to a national need for such estimates, considered new geological, technologic, and economic information, and used more definitive methods of resource appraisal than previous assessments.

The conventional resources assessed were (1) those considered *recoverable* under current technology and (2) those that could be developed and produced *economically* under specified price and cost relationships, excluding exploration costs. This study did not include resources from tar deposits, intractable heavy oil deposits, oil shales, gas in low-permeability (less than 0.1 millidarcy in situ) "tight" reservoirs, coal bed methane, gas in geopressured shales and brines, and natural gas hydrates (clathrates).

For this study, the United States was divided into 13 regions (9 onshore and 4 offshore), including the Exclusive Economic Zone (EEZ). The 13 regions were further divided into 115 provinces (appendix A, figs. A1 and A2). The resource estimates were based fundamentally upon review and analysis of petroleum geology and the exploration history of oil and gas plays in these provinces. Probability procedures were used in their derivation. Because of the uncertainty in estimating undiscovered resources, the estimated quantities are reported as a range of values that correspond to different probability levels.

The undiscovered *recoverable* conventional resources of oil for the United States, as of January, 1, 1987, are estimated to range from 33 to 70 billion barrels, with a mean estimate of 49 billion barrels; the estimates of gas range from 307 to 507 trillion cubic feet, with a mean estimate of 399 trillion cubic feet (table 1). Range estimates correspond to 95-percent probability (19 in 20 chance) and 5-percent probability (1 in 20 chance) of there being *more than* those amounts, respectively. Corresponding estimates for natural gas liquids (NGL) range from 6 to 12 billion barrels, with a mean estimate of 9 billion barrels.

Further, the assessed undiscovered *economically recoverable* oil and gas resources for the United States, as of January 1, 1987, are estimated to range from 21 to 54 billion barrels of oil and 208 to 326 trillion cubic feet of gas, corresponding to the 95-percent and 5-percent probabilities of there being more than these amounts, respectively (table 1). The mean value for oil is 35 billion barrels and for gas is 263 trillion cubic feet. Corresponding estimates for NGL range from 5 to 8 billion barrels, with a mean of 6 billion barrels. Distribution of these resources by region is shown in figure 1.

Manuscript approved for publication March 6, 1989.

INTRODUCTION

In 1981, the U.S. Geological Survey (USGS) published the results of a national assessment of undiscovered oil and natural gas resources for the United States, including the Outer Continental Shelf (OCS) (Dolton and others, 1981). In 1982, the Minerals Management Service (MMS) was formed for resource management of the OCS, and in 1985 MMS published estimates of undiscovered oil and natural gas resources for the Federal offshore areas (Cooke, 1985).

The two Agencies in 1985 agreed to undertake a cooperative resource assessment of the total United States to determine estimates of undiscovered conventional oil and natural gas. This report provides estimates for the onshore and offshore geologic provinces of the Nation and summarizes the data sources, assumptions, and methodologies that were used in the development of these estimates. The data, assumptions, and methodologies differ from those used in

Table 1. Estimates of undiscovered recoverable and undiscovered economically recoverable conventional petroleum resources for the United States

[Mean value totals may not be equal to the sums of the component means given elsewhere because numbers have been independently rounded. Fractile values (F_{95}–F_5) are not additive. Gas includes both nonassociated and associated-dissolved gas. BB, billion barrels; TCF, trillion cubic feet; NGL, natural gas liquids. F_{95} represents a 19 in 20 chance and F_5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated]

	Oil (BB)			Gas (TCF)			NGL (BB)		
	F_{95}	Mean	F_5	F_{95}	Mean	F_5	F_{95}	Mean	F_5
Undiscovered recoverable petroleum resources									
Onshore	18.0	30.7	47.8	170.9	242.6	330.7	4.7	6.4	8.5
Offshore (Fed. and State)	9.4	18.8	32.5	101.1	156.6	228.1	0.8	2.2	4.7
Entire United States	33.2	49.4	69.9	306.8	399.1	507.2	6.1	8.6	11.5
Undiscovered economically recoverable petroleum resources									
Onshore	13.9	24.6	39.2	142.0	182.2	228.9	3.9	5.3	6.9
Offshore (Fed. and State)	4.3	10.2	19.6	47.6	80.6	125.1	0.3	1.0	2.3
Entire United States	20.7	34.8	53.8	208.2	262.7	325.5	4.6	6.3	8.4

previous assessments and are described in detail in a joint USGS–MMS working paper, U.S. Geological Survey Open-File Report 88–373. This report summarizes the working paper and, in addition, contains total estimates of the Nation's conventional undiscovered oil and gas resources.

This publication presents estimates of undiscovered conventional oil and natural gas resources as of January 1, 1987. Additional data received after that date are not incorporated in this assessment. The estimates are based upon a coordinated assessment of the known and possible petroleum-bearing onshore and offshore geologic provinces of the United States. Estimates for the onshore geologic provinces and adjoining State offshore areas were developed by the USGS. Estimates for the Federal offshore areas of the United States were developed by the MMS.

Great uncertainties are inherent in estimating undiscovered quantities of oil and gas. The estimates in this report are derived from judgments based upon a variety of geologic data, records of exploration successes and failures, production histories, assumptions concerning economic and technological conditions, and several appraisal methods. Both agencies used methodologies developed to assist in making decisions under conditions of uncertainty. The methodologies were appropriate to the data available, and the results are presented as ranges of values with associated probabilities of occurrence. Oil and gas plays were the basic building blocks for the assessment.

The estimates presented in this report should be viewed as indicators of the petroleum potential of the geologic provinces and regions. The assessment is based on the understanding of petroleum geology developed within the two agencies over time and specifically incorporates geologic, engineering, and economic data resulting from petroleum exploration and development activities in the various geologic provinces since the earlier publications (Dolton and others, 1981; Cooke, 1985).

For the purposes of this assessment, the United States was divided into nine onshore regions consisting of 80 geologic provinces and four offshore regions consisting of 35 geologic provinces. The regions correspond, in general, to those addressed by USGS Circular 860 and those addressed by MMS OCS Report 85–0012 (both cited above). The offshore areas include the OCS Exclusive Economic Zone (EEZ) adjacent to the lower 48 States and Alaska. Hawaii and the Trust Territory of the Pacific Islands were not included.

The information presented herein regarding known reserves of discovered oil and natural gas was derived from separate sources for the onshore and offshore areas. The reserve estimates for the onshore and State offshore areas were derived from data published by the Energy Information Administration (EIA) of the U.S. Department of Energy, specifically EIA's publication entitled "U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves—1986 Annual Report" (1987a). The reserve estimates for the Federal offshore areas are based upon data published by the MMS in two reports: "Estimated Oil and Gas Reserves, Gulf of Mexico, December 31, 1986" (Hewitt and others, 1987) and "Estimated Oil and Gas Reserves, Pacific Outer Continental Shelf, December 31, 1986" (Raftery and Wolfson, 1987). Published MMS reserve estimates were supplemented in this report to include estimates for fields that lacked estimates at the time the earlier publications were prepared, or, in the case of Alaska offshore areas, supplemental information from published reports is presented in lieu of proprietary reserve estimates.

COMMODITIES ASSESSED

The commodities assessed in this study are crude oil, natural gas, and natural gas liquids that exist in conven-

Figure 1. Distribution of estimated undiscovered recoverable conventional oil and gas resources of the United States by region. Figures are reported as a range of values, at 95-percent and 5-percent probabilities, in billions of barrels for oil and trillions of cubic feet for gas. State waters are included in onshore estimates. Oil figures are slanted; gas figures are vertical. Respective range values are not additive and must be aggregated by probability methods.

tional reservoirs. *Crude oil* is a mixture of hydrocarbons that is present in a liquid state in underground reservoir rocks and remains in a liquid state as it is produced from wells. *Natural gas* is a mixture of gaseous hydrocarbons classified by occurrence into the following categories:

Associated gas—free natural gas, occurring as a gas cap, in contact with and above an oil accumulation within the reservoir;

Dissolved gas—natural gas dissolved in crude oil within the reservoir; and

Nonassociated gas—natural gas that is not associated with or not in contact with crude oil within a reservoir.

Natural gas liquids (NGL) are "those portions of reservoir gas that are liquefied at the surface in lease separators, field facilities, or gas processing plants. Natural gas liquids include but are not limited to ethane, propane, butanes, pentanes, natural gasoline, and condensate" (American Petroleum Institute, 1976, p. 6). Both oil and natural gas normally include small quantities of various nonhydrocarbon impurities.

Amounts of oil and gas are reported as standard stock tank barrels of crude oil (42 gallons per barrel) and standard cubic feet of gas (14.73 pounds per square inch and 60 °F), respectively. Gas estimates include volumes of hydrocarbon gases only.

The estimates of conventional resources in this report do not include resources from very heavy oil deposits or tar deposits, oil shales, gas from low-permeability "tight"

sandstone reservoirs, fractured shale reservoirs having in situ reservoir permeabilities to gas less than 0.1 millidarcy, coal bed methane, gas in geopressured shales and brines, or gas hydrates. These kinds of occurrences, however, are recognized as important future sources of hydrocarbons, and some oil and gas production is currently derived from them. For example, some gas is produced from fractured shales and low-permeability sandstones in the Appalachian basin, and some gas is produced from low-permeability sandstones in the Rocky Mountains, Colorado Plateau, Mid-Continent, and Gulf Coast regions. Also, some coal bed methane is produced in the Black Warrior and San Juan basins. Geopressured methane has been produced in the Gulf Coast basins, and some oil has been produced from shallow heavy oil deposits in Missouri and Kentucky.

There are two principal reasons for excluding these kinds of unconventional resources from this study. First, they are, for the most part, discovered, and their geographic and stratigraphic distribution is largely known. This study assesses *undiscovered* conventional oil and gas resources. Secondly, in many instances, they contain very large in-place volumes of hydrocarbons of such uncertain recoverability, because of economics and extraction technology, that they represent a class of resources that is best treated separately, particularly with reference to estimates of available recoverable resources. These occurrences require a level of geologic data and interpretation that is not generally available in order to support engineering and economic studies needed to assess their recoverability. A discussion of resources in several of these categories is presented in the USGS–MMS Working Paper, Open-File Report 88–373, and in Fisher and others (1988). Although considered "unconventional" for the purposes of this joint assessment, portions of these types of occurrences are sometimes included in oil and natural gas resource estimates and in reserve estimates by others using different assumptions of recoverability.

In some geologic settings, the boundary between conventional and unconventional resources is gradational and, given the data available, difficult to draw. In some areas it is nearly impossible to completely separate unconventional resources from conventional resources. However, we have not included large volumes of unconventional resources, nor have we excluded large volumes of conventional resources from the estimates. There is little question that unconventional resources will require much more study to determine their long-term impact on the oil and gas resource picture.

Estimates of undiscovered resources do not include reserve estimates, nor do they include volumes that may yet be found in new pay zones in known fields or extensions to known fields. The latter are reported as inferred reserves and are shown schematically on figure 2.

The estimates presented in the report are provided in two categories: (1) undiscovered recoverable resources and (2) undiscovered economically recoverable resources. Undiscovered recoverable resources are in undiscovered accumulations analogous to those in existing fields and are producible with the current recovery technology and efficiency but without reference to economic viability. These accumulations are generally of sufficient size to be amenable to conventional recovery technology. These resources occupy the area of the heavily framed box in figure 2.

Undiscovered economically recoverable resources are those resources assessed in the undiscovered recoverable resources category that are economically recoverable under conditions of current technology and imposed economic criteria. The estimates of the economically recoverable resources were predicated upon a January 1, 1987, oil price of $18 per barrel and a natural gas price of $1.80 per thousand cubic feet (MCF), with adjustments over future years for price and cost progressions and other economic factors influencing industry development activity in the United States (a more detailed discussion appears in the section "Economic Parameters"). Exploration costs were not included. Except for the onshore lower 48 States, where pipelines are generally in place, oil and gas transportation and pipeline development costs were included. Undiscovered accumulations were assigned a January 1, 1987, discovery date and then were determined to be economically recoverable if projected cash flows were sufficient to pay development and operating costs and to provide an after-tax rate of return averaging 8 percent. This analysis eliminates from the economic category all estimated accumulations smaller than the calculated minimum economic field size (MEFS), and its impact is most significant in high-cost operating environments such as the Arctic and offshore. The economically recoverable resources occupy the hachured area on the resources classification chart (fig. 2).

Estimates of reserves are included to provide a measure of those resources that have been identified (discovered) and to provide a frame of reference for analyzing the undiscovered quantities. Reserve estimates are developed from the Energy Information Administration data (1987a) and from the MMS reserves studies.

TERMINOLOGY

The terminology in this report represents standard definitions and usage practiced by the oil and natural gas industry and the resource estimation community. A detailed listing of common industry definitions is not included; however, several definitions that are essential to the proper understanding of the information in this report are presented. These definitions should be viewed as general explanations rather than strict technical definitions of the terms being addressed.

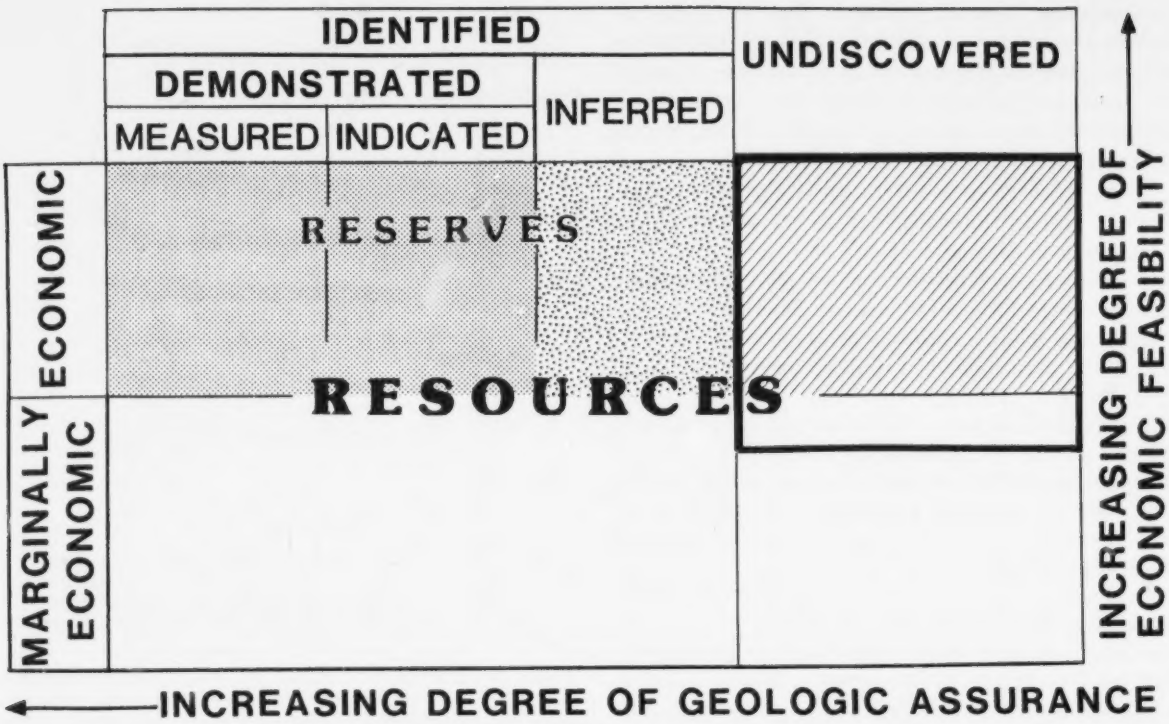


Figure 2. Diagrammatic representation of petroleum resource classification (modified from U.S. Bureau of Mines and U.S. Geological Survey, 1980). The figure represents conventional oil and gas resources. The area within the heavy frame on the upper right represents the undiscovered recoverable resources estimated in this study. The hachured area within the heavy frame indicates the quantities of undiscovered resources that are estimated to be economically recoverable.

Undiscovered resources.—Resources estimated to exist, on the basis of broad geologic knowledge and theory, outside of known fields or known accumulations. Also included are resources from undiscovered pools within known fields to the extent that they occur as unrelated accumulations controlled by distinctly separate structural features or stratigraphic conditions.

Undiscovered recoverable resources.—Resources in undiscovered accumulations analogous to those in existing fields producible with current recovery technology and efficiency but without reference to economic viability. These accumulations are considered to be of sufficient size and quality to be amenable to conventional recovery technology. These resources occupy the area of the heavily framed box in figure 2.

Undiscovered economically recoverable resources.—Part of the undiscovered recoverable resource category that is economically recoverable under conditions of current conventional technology and imposed economic assumptions. The economically recoverable resources occupy the hachured area on the resources classification chart (fig. 2).

Conventional resources.—Resources included in this category are crude oil, natural gas, and natural gas liquids that exist in conventional reservoirs or in a fluid state amenable to extraction techniques employed in traditional development practices, as indicated below. They occur as discrete accumulations.

They do not include oil occurring within extremely viscous and intractable heavy oil deposits, tar deposits, or oil shales, or gas from low-permeability "tight" sandstone and fractured shale reservoirs having in situ permeabilities to gas of less than 0.1 millidarcy, coal bed methane, gas in geopressured shales and brines, or gas hydrates.

Conventionally recoverable resources.—Oil and natural gas resources that may be produced at the surface from a well bore as a consequence of natural pressure within the subsurface reservoir; artificial lifting of oil from the reservoir to the surface, where economically applicable; and the maintenance of reservoir pressure by means of water or gas injection.

Measured reserves.—Part of the identified economic resource that is estimated from geologic evidence supported directly by engineering data. They are demonstrated with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions (fig. 2) and are generally equivalent to "proved reserves" (Energy Information Administration, 1987a).

Indicated reserves.—Reserves that are in known productive reservoirs in existing fields, in addition to measured reserves, expected to respond to improved recovery techniques, such as fluid injection, (1) where an improved recovery technique has been installed, but its effects are not yet known or (2) where an improved technique has been installed in another similar reservoir, and the results of that installation can be used to estimate the quantity of additional resources (fig. 2).

Inferred reserves.—That part of the identified economic resources, over and above measured and indicated reserves, that will be added through extensions and revisions and with the addition of new pay zones in discovered fields (fig. 2).

Oil-equivalent gas.—Gas volume that is expressed in terms of its energy equivalent in barrels of oil (BOE). Approximately 6,000 cubic feet of gas equals one BOE.

Field.—A single pool or multiple pools of hydrocarbons grouped on, or related to, a single structural or stratigraphic feature.

Prospect.—A geologic feature having the potential for trapping and accumulating hydrocarbons.

Play.—A group of geologically related known accumulations or undiscovered accumulations and (or) prospects having similar hydrocarbon sources, reservoirs, traps, and geologic histories.

Cumulative probability distributions.—The resource estimates are derived in the form of cumulative probability distributions (fig. 3). These distributions include the resource estimates reported in this publication: a low estimate having a 95-percent probability (19 in 20 chance) of at least that amount (F_{95}), a high estimate having a 5-percent probability (1 in 20 chance) of at least that amount (F_5), and a mean estimate representing an average of all of the possible resource outcomes. These cumulative probability distributions can be either conditional or risked (unconditional).

Conditional estimates.—Estimates of the volumes of undiscovered oil or natural gas in an area, given the condition that undiscovered recoverable oil or natural gas actually occurs. For economically recoverable resources, the condition is that one or more undiscovered commercial accumulations of hydrocarbons exist in the area. Conditional estimates, therefore, do not incorporate the risk that the area may be devoid of the hydrocarbons assessed.

Marginal probability of hydrocarbons.—An estimate, expressed as a decimal fraction, of the chance that oil or natural gas exists in an area. The marginal probability is the complement of the risk (1 minus the risk) that an area is devoid of hydrocarbons. For recoverable resources, the marginal probability represents the probability that oil or natural gas exists in at least one accumulation of the minimum size assessed. For economically recoverable resources, the marginal probability represents the chance that commercial quantities of oil or natural gas exist in at least one accumulation in the area being assessed, under the economic conditions and price scenario applicable to the assessment.

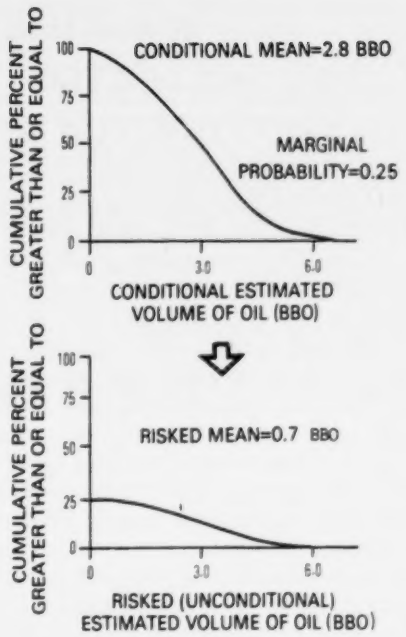


Figure 3. Example of cumulative probability distributions for estimated resources showing relationship between conditional and risked (unconditional) estimates. BBO, billion barrels of oil.

Risked (unconditional) estimates.—Estimates of the volumes of oil or natural gas that may exist in an area, including the possibility that the area is devoid of oil or natural gas. The risked mean quantity may be determined through multiplication of the mean of a conditional distribution by the related marginal probability (fig. 3). However, other points of the risked distribution must be determined by use of probabilistic methods. *Estimates presented in this report are risked (unconditional) estimates,* with the sole exception of those presented in appendix B.

AREAS OF STUDY

The oil and gas resources of the United States were evaluated on the basis of interpretation of the geology of its petroleum provinces. For this study, the United States was divided into 13 petroleum regions, 9 onshore and 4 offshore (fig. 4). These regions correspond in general to those appraised in 1980 (Dolton and others, 1981) and 1984 (Cooke, 1985). The onshore regions include State water areas. The offshore areas, designated by the letter "A" after the region number, include the Outer Continental Shelf and

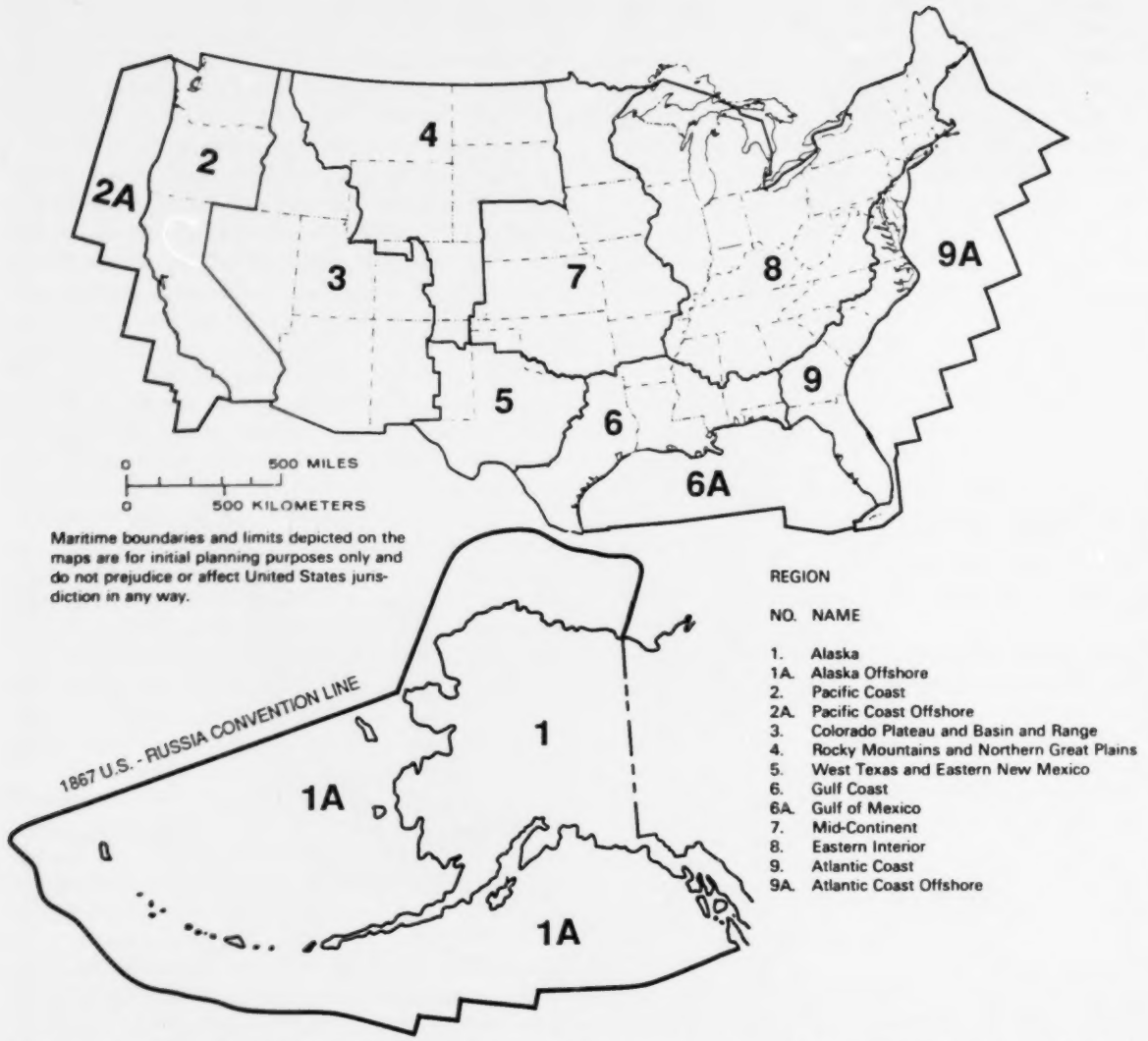


Figure 4. Petroleum regions assessed in this study. Heavy lines are region boundaries; dotted lines are State boundaries.

the Exclusive Economic Zone adjacent to the lower 48 States and Alaska. The 13 regions were further divided into 115 provinces (appendix A, figs. A1 and A2). Hawaii and the Trust Territory of the Pacific Islands were not included.

The regions shown in figure 4 are geographic in character; however, their formulation represents an attempt to group the individual petroleum provinces along broad geologic lines (provinces are shown in detail in appendix A).

Individual provinces are based on natural geologic entities and may include a single dominant structural element or a number of contiguous elements. Their boundaries, following State and county lines where possible, facilitate the use of production, reserve, and other data reported for political units. Provinces were named for structural or geographic features within their boundaries.

GEOLOGIC FRAMEWORK

The distribution of oil and gas resources in the United States is best understood within the framework of the geology of the North American continent. In essence, the continent consists of a relatively stable interior surrounded by zones of more highly deformed rocks (fig. 5). The Canadian Shield is an outcrop of the old, tectonically stable

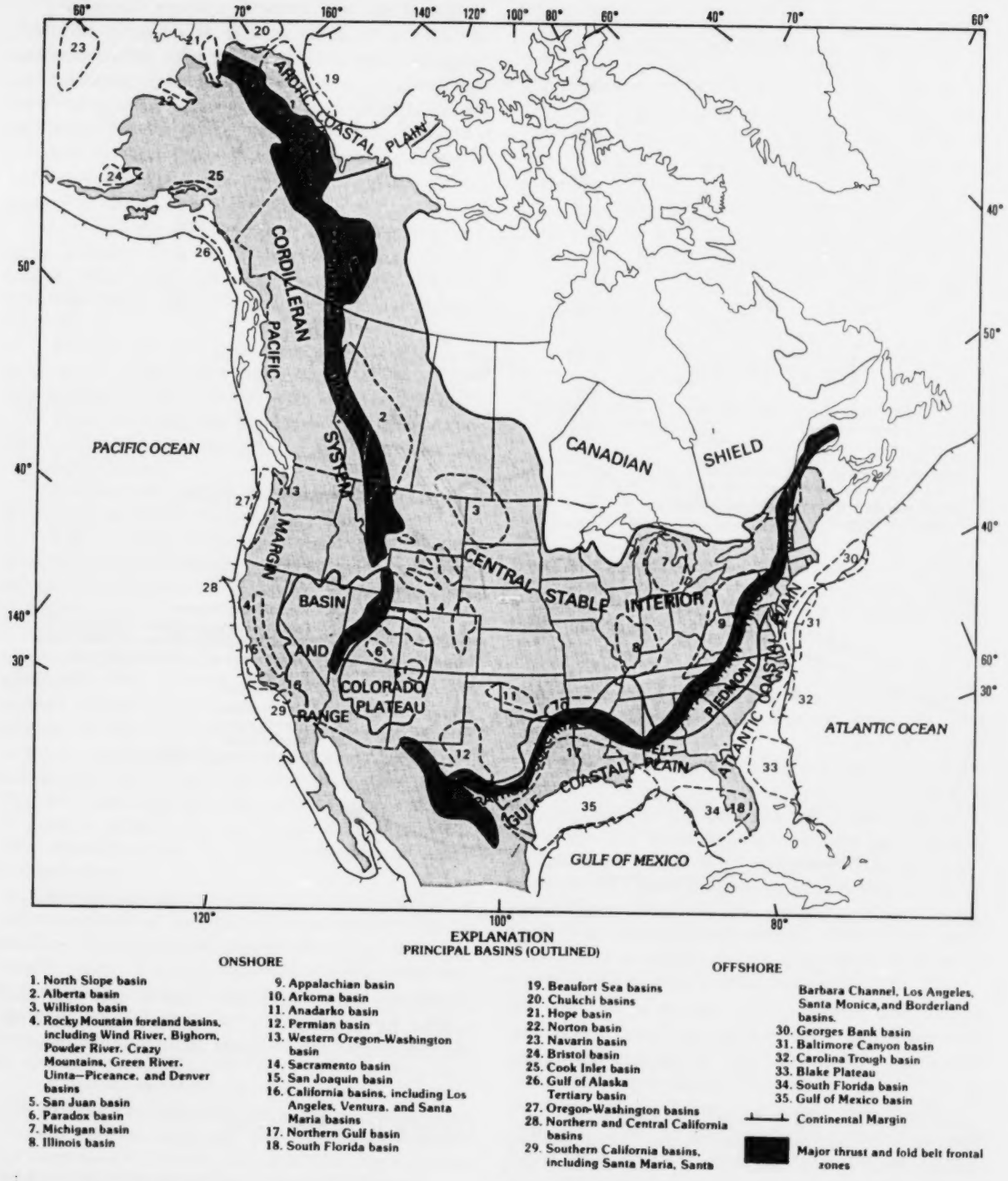


Figure 5. Generalized tectonic map of North America showing principal sedimentary basins (modified from King, 1977).

rocks that form the core of the continent. These igneous and metamorphic rocks are generally not prospective sites for petroleum. In the Central Stable Interior, similar crystalline rocks are overlain by a relatively thin cover of sedimentary rock filling a number of structurally uncomplicated basins separated by broad arches that contain abundant hydrocarbon resources. Regional deformation of margins of this Central Stable Interior is particularly strong at its western and southern sides. Basins at the margin of the Central Stable Interior tend to be deeper and structurally more complex than those of the interior and are often highly productive of oil and gas, as typified by the Permian and Anadarko basins.

Belts of rock deformed by intense folding and thrusting ring the Central Stable Interior. These are the Cordilleran thrust belt, which stretches from Alaska to Mexico, the Appalachian thrust belt, the Ouachita thrust belt, and the Marathon thrust belt. They locally contain significant hydrocarbon resources.

East of the Appalachian thrust belt are the crystalline rocks of the Piedmont. Mesozoic and Cenozoic sedimentary rocks of the Atlantic Coastal Plain lap onto the Piedmont to form a wedge of sedimentary rocks that thickens seaward along most of the Atlantic margin. Mesozoic and Cenozoic sedimentary rocks of the Gulf Coastal Plain similarly lap onto the Marathon and Ouachita thrust belts and form a wedge that thickens into the Gulf of Mexico.

The Cordilleran System, the major structural element of western North America, also includes major subelements, particularly the Basin and Range and the Pacific margin. The complex structures of this part of the continent suggest that it has been tectonically active throughout much of Phanerozoic time.

Alaska is divided into two major structural elements. The northern element consists of the Brooks Range, which is part of the Cordilleran thrust belt, and all areas north to the Arctic Ocean. The southern element includes all of Alaska south of the Brooks Range and has a different and more complex geologic history than does the northern element.

Areas of the United States that have produced oil and gas are shown in figure 6, and the ages of major productive and prospective rocks in each region are shown in figure 7. The Central Stable Interior (Regions 5, 7, 8, and parts of 4) produces mainly from relatively old rocks of Paleozoic age. To the west, in Regions 3 and 4, petroleum in the intermontane and foreland basins is produced from rocks of Paleozoic and Mesozoic age and, in some instances, Cenozoic age.

The thrust belts of the Cordilleran System produce oil and gas from Mesozoic and Paleozoic reservoir rocks, whereas the Ouachita and Appalachian thrust belts include only Paleozoic reservoirs.

A thick sequence of Mesozoic and Cenozoic sedimentary rocks characterizes both the Gulf and Atlantic margins. In the Gulf Coastal Plain (Region 6) and adjoining Gulf of Mexico (Region 6A), these young rocks have produced large quantities of hydrocarbons. Other than peninsular Florida, the Atlantic margin (Regions 9 and 9A) has not produced commercial amounts of petroleum; however, noncommercial discoveries of gas have been made in Mesozoic rocks of the offshore Baltimore Canyon area.

A series of productive sedimentary basins extends from New Mexico through Montana east of the Cordilleran System and at the west margin of the Central Stable Interior, including the Colorado Plateau (parts of Regions 3 and 4). Hydrocarbon production in this area is from rocks of Paleozoic, Mesozoic, and Cenozoic age. Within the Basin and Range, only minor production has been established. To the far west, at the Pacific margin (Region 2) are the very rich Cenozoic basins of coastal California and the Mesozoic-Cenozoic basins of the Great Valley.

Alaska's production (Regions 1 and 1A) is from two areas. Cook Inlet, in southern Alaska, produces from rocks of Cenozoic age; more importantly, the Arctic Coastal Plain of the North Slope, which includes the supergiant Prudhoe Bay field, produces from rocks of Paleozoic, Mesozoic, and Cenozoic age.

The following regional discussions outline the geology of the United States as related to known and prospective petroleum potential, generally from west to east. These discussions represent a very brief synthesis of the petroleum geology of each region. The petroleum production, reserves, and resource potential of each region are shown by table 2 (p. 19).

Onshore Regions and State Waters

Region 1, Alaska

The geology of Region 1 is varied and complex. Much of the region is composed of a vast mosaic of crustal terranes that have accreted to the ancestral North American cratonic margin. Associated with this complex are sedimentary basins, some of which have been strongly deformed and contain altered rocks of little petroleum potential. However, many younger, less deformed basins contain significant potential. The most significant in terms of petroleum are the composite basins, such as the North Slope basin, which encompasses the northern part of the Brooks Range and the Arctic Coastal Plain, including parts of the offshore (fig. 5). Large quantities of oil and gas are present in Triassic reservoirs at Prudhoe Bay field (the largest oil field in North America), Mississippian reservoirs at Endicott field, and in Tertiary reservoirs at Kuparuk River field. Significant additional potential is estimated in Paleozoic, Mesozoic, and Tertiary reservoirs in this basin, including the highly folded rocks of the northern Brooks Range.

Nonmarine basins containing Cenozoic rocks constitute the most numerous of Alaskan basins but are poorly

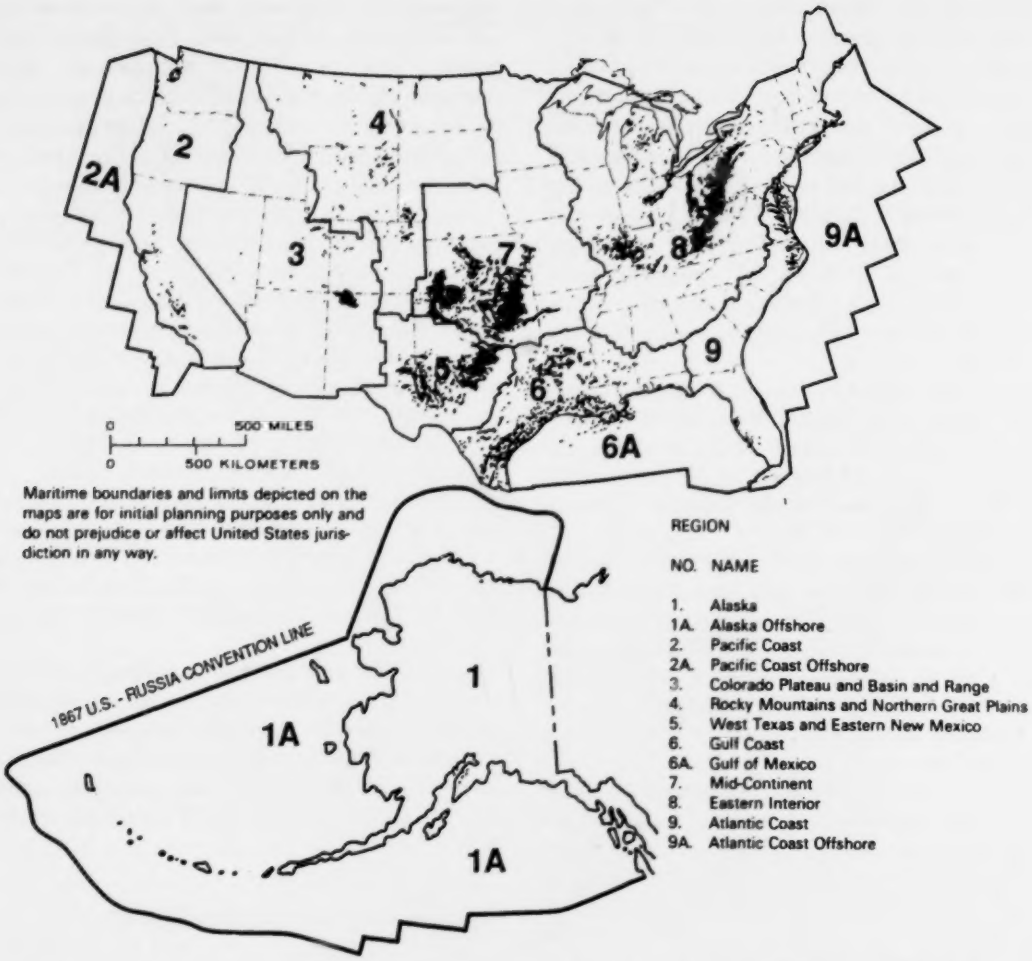


Figure 6. Map of petroleum regions and general distribution of oil and gas fields in the United States (modified from Vlissides and Quirin, 1964).

known because of extensive alluvial cover. In general, they occupy the interior parts of Alaska. The Cook Inlet basin, the best known example, contains large accumulations of oil and gas onshore and in State waters. These basins are characterized by nonmarine fill and are often associated with major faulting. Reservoirs are primarily sandstones. Most of these basins are considered to be gas prone, and undiscovered resources are estimated to be small.

Basins containing Cenozoic marine rocks are most commonly found on the Bering Sea and Pacific margins of Alaska. They include the Bristol and Gulf of Alaska basins. Those of the Pacific margin generally lie in a forearc setting and have accumulated thick sequences of Tertiary marine sediments, including transported terranes. Significant hydrocarbon accumulations have not yet been discovered in these areas, and the potential appears limited by poor reservoir and source-rock characteristics.

The considerable petroleum potential of onshore Alaska is concentrated in the North Slope region, about equally distributed between the coastal plain and foothills areas of the North Slope basin. Development of future discoveries on the North Slope and elsewhere in onshore Alaska will be strongly influenced by the proximity of those discoveries to the existing pipeline system.

Region 2, Pacific Coast

Because of the active tectonic history of this region, during which older basins have been destroyed and new ones created, rocks prospective for petroleum are limited mostly to basins that formed during Mesozoic and Cenozoic time.

Most of western Oregon and Washington is the site of a forearc basin composed of great thicknesses of sedimen-

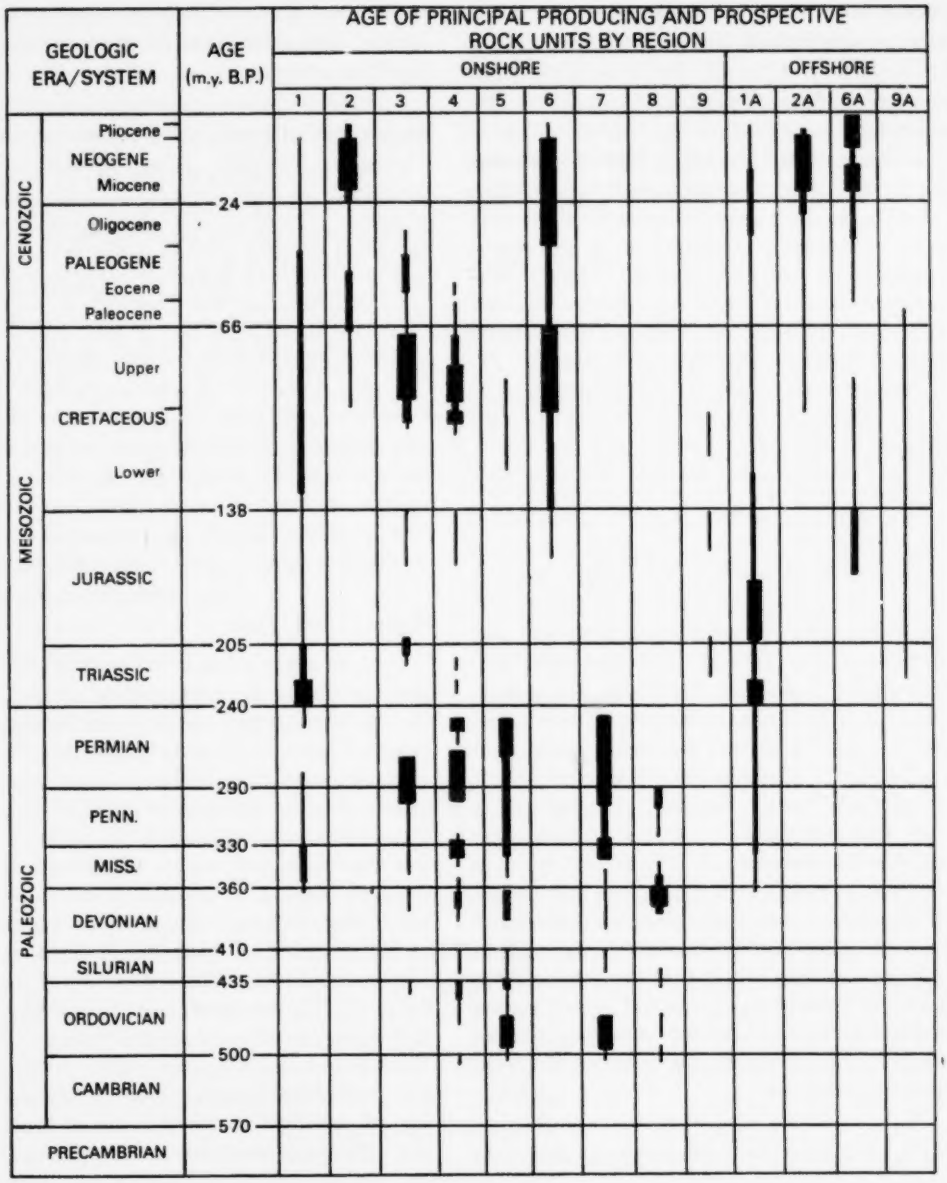


Figure 7. Age and importance of principal producing and prospective reservoir rocks by region. Width of bar is proportional to significance of reservoir. See figure 6 for names of numbered regions.

tary and volcanic rocks of Tertiary age. The area is complexly folded and faulted, and only small occurrences of gas and scattered shows of oil have been reported to date.

Most of eastern Oregon and Washington and part of northeastern California is a high plateau composed of a thick volcanic cover. Because of this cover, the basins in the region are poorly defined and prevolcanic rocks not well understood; however, thick sequences of Tertiary sedimentary rocks are known to be present locally beneath the volcanics and are considered to have potential for gas resources.

The Great Valley of California, composed of the San Joaquin and Sacramento basins, is a forearc basin that has a thick sequence of marine and nonmarine rocks, which range in age from Late Jurassic to Holocene. The Great Valley is highly productive of gas in the north and of oil in the south.

The area has a long history of exploration, but future potential appears rather limited. Undiscovered resources are postulated to be in deeper parts of the basins, in subtle traps, in complex traps within producing trends, and in a few relatively unexplored areas.

The California coastal basins are located south and west of the Great Valley. They are small but typically contain very thick Neogene sedimentary rock fill. Several of these basins have been exceedingly rich in discovered petroleum, particularly the Los Angeles, Ventura, and Santa Maria basins. Principal producing zones are Miocene and Pliocene rocks, primarily sandstones and fractured siliceous rocks. Because of the extent of exploration, the potential for undiscovered resources in these areas is considered modest, with most of the undiscovered oil believed to be in deep parts of the basins, in subtle traps, in complex traps in producing trends, and in other areas that have been explored incompletely.

Region 3, Colorado Plateau and Basin and Range

The geology of this region is exceedingly diverse and complex. Major structural elements reflect Laramide and post-Laramide tectonism. Many of the basins within the region are structural basins formed during this period. However, also included are several basins of Paleozoic age, a major thrust belt, a portion of an extensive rift system, and a buried thrust belt that has a surface tectonic overprint of basin and range block faulting. Reservoir rocks are varied, ranging in age from Ordovician to Tertiary, and include both sandstones and carbonates.

The intermontane basins of the region, such as the Uinta-Piceance and San Juan basins, and the Cordilleran thrust belt are particularly important in terms of petroleum resources. Major oil and gas fields have been found in these areas. To date, only a few fields have been discovered in the lightly explored Basin and Range area. Some basins in the region also host thick "tight gas sand" sequences, which are not the subject of this report.

Region 4, Rocky Mountains and Northern Great Plains

This region is characterized by many Laramide intermontane basins, such as the Powder River and Bighorn basins, which are separated by major uplifts; the cratonic Williston basin; several major Paleozoic paleostructural elements; and the Montana part of the Cordilleran thrust belt. Nineteen separate sedimentary basins are included here. Producing reservoirs are clastic and carbonate rocks that range in age from Cambrian to Tertiary.

Exploration in this region has resulted in the discovery of major reserves of oil and gas, including several giant fields. Most of the larger fields are structurally controlled; however, recent exploration has led to exploitation of many stratigraphic traps. The potential for undiscovered hydrocarbons varies greatly within the region, but overall, substantial undiscovered resources remain. This region also contains large volumes of gas in unconventional ("tight gas sand") reservoirs.

Region 5, West Texas and Eastern New Mexico

The main structural elements of the area include the Permian basin, the Bend arch-Fort Worth basin area, and the Marathon-Ouachita thrust belt on the south. Almost the entire Paleozoic section of the region is productive. The Permian basin is a large asymmetric structural depression on the southwestern margin of the North American craton that has filled with a thick Paleozoic rock sequence. Region 5 is second only to the Gulf Coast Region (Region 6) in cumulative production of oil and gas in the United States, and the Permian basin is the most prolific part. The Permian basin is also the most important area in the region for undiscovered resources; the Bend arch-Fort Worth basin area is a distant second. The Delaware-Val Verde portion of the Permian basin is particularly important for gas.

Region 6, Gulf Coast

This region consists fundamentally of a large, compound Mesozoic and Cenozoic basin or geocline formed on the southern margin of the North American continent. Several subbasins occur within it. Thick, seaward-offlapping wedges of sediment have accumulated above widespread Jurassic salt deposits and localized salt basins. The overall basin, known as the Northern Gulf basin, is characterized by deformation associated with gravity movements and flowage of salt and underconsolidated Cenozoic sediments. The northern basin rim is bounded by a series of arcuate growth fault systems that are downthrown to the south and by similar, but younger, parallel fault systems to the south. Salt domes of great vertical relief penetrate the sedimentary section and are prevalent over large areas.

Mesozoic rocks in the region contain both sandstone and carbonate reservoirs; however, Cenozoic rocks, which are the principal exploration targets in the region, are characterized by sandstones of excellent reservoir quality. The region contains a wide spectrum of traps, including growth fault and rollover structures, salt domes, anticlines and faulted structures, and a variety of stratigraphic traps.

The region, the most prolific petroleum region in the United States (see table 2), contains a large number of giant fields, including the old East Texas field, which is an immense stratigraphic trap, and recent major discoveries in the deep Jurassic section. The Gulf Coast Region continues to have significant potential for undiscovered resources of both oil and gas.

Region 7, Mid-Continent

This region occupies a large part of the Central Stable Interior and contains two deep basins, the Anadarko on the

west and the Arkoma on the east, both containing very thick sequences of Paleozoic rocks. A series of shallow basins that are separated by broad uplifts occurs along the northern margin. The region is bounded along its southern margin by the strongly deformed Marathon-Ouachita thrust belt and by a complex of major mountain uplifts and associated basins.

Oil in this region is concentrated in the States of Kansas and Oklahoma. Traps are, variously structural, stratigraphic, or a combination of both, and reservoirs are sandstones and carbonates of Paleozoic age. Over half the oil in Kansas occurs on a regional high, the Central Kansas uplift. The major gas field in the region, the Hugoton-Panhandle field, occupies parts of Kansas, Oklahoma, and Texas and is on the western side of the Anadarko basin. Large gas resources have also been found in the Pennsylvanian sandstones of the Arkoma basin in Arkansas and Oklahoma. Oklahoma's major oil-producing areas include the Anadarko basin and the shelf areas and uplifts bordering it to the north and east. Significant undiscovered resources are believed to exist in the region, largely in lesser explored areas, such as the deep Anadarko basin.

Region 8, Eastern Interior

This region comprises several large basins and uplifts within the eastern part of the craton. Two major intracratonic basins, the Michigan and Illinois basins, are separated from the Appalachian basin to the east by the Cincinnati Arch and Nashville Dome. The east side of the foreland Appalachian basin is bounded by the highly deformed rocks of the Appalachian thrust belt.

The major producing areas in the region are the Appalachian, Michigan, and Illinois basins. Reservoirs in these basins include both sandstones and carbonates, ranging in age from Cambrian to Pennsylvanian. Not only are structural traps important, but much oil and gas is trapped stratigraphically. Although exploration is in a very mature stage in this region, significant undiscovered resources are believed to exist. Currently, significant discoveries are being made in deep Cambrian-Ordovician clastic reservoirs and in Silurian pinnacle reefs of the Michigan basin.

Region 9, Atlantic Coast

The Atlantic Coast Region, which extends through peninsular Florida, embraces both early Mesozoic rift basins and an overlying wedge of younger rocks. Elongate, extensional rift basins containing Upper Triassic and Lower Jurassic rocks of nonmarine origin are found exposed in the Appalachian Piedmont from Georgia to northern Massachusetts and are inferred to occur beneath the coastal plain sediments. Sedimentary rocks of the coastal plain that cover these basins include largely terrigenous clastics and marine carbonates of late Mesozoic, Cenozoic, and Holocene age. From north to south, these younger rocks become increasingly carbonate rich; south of the Peninsular Arch in Florida, the sediment wedge becomes almost exclusively carbonate and anhydrite and thickens into the South Florida basin.

Although a small amount of oil has been found in the South Florida basin, oil production has not been established elsewhere in the region, and the Atlantic Coastal Plain generally appears to have little petroleum potential.

Federal Offshore Regions

Region 1A, Alaska Offshore

The Alaska region can be divided into three areas of significant geologic uniformity: (1) the Arctic subregion, including the Beaufort, Chukchi, and Hope areas, (2) the Bering Sea subregion, and (3) the Gulf of Alaska, which also includes Cook Inlet. The Arctic subregion has the highest potential for significant future discoveries, particularly in the untested Chukchi Sea. In the Beaufort Sea, the offshore extension of coastal plain Ellesmerian rocks has resource potential.

Provinces in the Bering Sea subregion have smaller resource estimates as compared with the last assessment, largely as a result of disappointing drilling results, particularly in the once highly regarded Navarin basin. Twenty-four exploratory wells have been drilled in the Bering OCS with no discoveries. Geological analysis of the results of the drilling program shows that the lack of success can be attributed to poor source-rock characteristics. Additionally, reservoir sands tend to be contaminated with fine-grained particulates, and sealing lithologies are poorly developed.

Provinces in the Gulf of Alaska have significant potential for development. Wells drilled in the area have yielded noncommercial shows. However, the area tends to be gas prone, but gas is not currently considered to be commercially viable. Lower Cook Inlet appears to have little potential despite its proximity to production in adjacent State waters.

Region 2A, Pacific Coast Offshore

The geologic and petroleum framework of this region is characterized by an active history of faulting, earthquakes, and deformation that has resulted in destruction of older basins and creation of new ones. The deformation has produced numerous structures that may trap hydrocarbons, but the destruction of older basins has limited exploration targets mainly to younger rocks of Cenozoic age.

On the basis of geology and exploration history, the region can be subdivided into three parts: southern, central, and northern. In the southern part, from the Santa Barbara Channel southward, provinces offshore southern California comprise a mature producing area in which extensive leasing and exploration have resulted in the discovery of 14 significant fields. Reservoirs are dominantly sandstone of

Cenozoic age. In the central part, from the western Santa Barbara Channel to Cape Mendocino, provinces are anticipated to have fractured shale reservoirs of the Monterey and Point Arena Formations. The evidence from exploration wells drilled offshore in this play between 1964 and 1967, along with major discoveries in the Santa Maria basin province, demonstrates that this part of the Pacific OCS has the best chance for a significant discovery of petroleum north from southern California through the Bering Sea of Alaska. In the northern part, exploration in OCS provinces of northernmost California, Oregon, and Washington also occurred between 1964 and 1967, but evidence of significant economically recoverable quantities of petroleum was not encountered. Potential reservoirs in this part are primarily upper Cenozoic sandstone of low reservoir quality.

Region 6A, Gulf of Mexico Offshore

The Gulf of Mexico OCS separates naturally into two geological provinces: a Cenozoic province occupying the western two-thirds of the Gulf of Mexico, in which the producing horizons range in age from Oligocene to Pleistocene, and a Mesozoic province occupying roughly the eastern one-third of the Gulf of Mexico, in which production is largely concentrated in the Jurassic strata. Of these two provinces the Cenozoic has the highest potential for significant undiscovered oil and gas resources by a considerable margin. Future exploration and development activities are expected to focus on the continental slope, an area that includes the promising Flexure Trend.

Region 9A, Atlantic Coast Offshore

A thick, relatively undeformed, progradational wedge of Mesozoic and Cenozoic sedimentary deposits characterizes the Atlantic OCS. These deposits overlie lower Mesozoic and younger sedimentary rocks deposited in a series of elongate rift valleys that resulted from the opening of the Atlantic Ocean. The comparatively low heat flow of the region, combined with the inferred lack of numerous petroleum migration pathways through faults and folds, limits potential to the deeper Mesozoic rocks in thicker areas of deposition, mostly far from shore.

Forty-nine exploratory wells and five stratigraphic test wells have been drilled since exploration began off the Florida Keys in 1959. No commercial accumulations of hydrocarbons have been found, but a substantial show of noncommercial natural gas was encountered in the Baltimore Canyon province of the mid-Atlantic area. Some industry exploration may occur on current leases in the Carolina Trough province of the South Atlantic, where thick salt beds, similar to those of the productive Gulf of Mexico, may be present.

DATA BASE

The development of estimates for the undiscovered oil and natural gas resources for this assessment required the compilation and analysis of geologic, geophysical, engineering, and economic data from published and private sources throughout Government and industry. Descriptions of the data used by the USGS and MMS for their respective assessments are given below.

Onshore Regions and State Waters

Analyses of the onshore and State offshore provinces by the USGS were based on nonproprietary data that either are published, available from commercial sources, or available from USGS studies in progress.

Province geologists used data from previous assessments, published data (particularly from State geological surveys), and interpretations of geological, geochemical, and geophysical data from all pertinent sources to develop the oil and gas play framework for the assessments. Open-file reports, now being prepared by the province geologists for each assessment area, describe (1) the petroleum geology of the basins or provinces and (2) the geology of the oil and gas plays.

Computerized drilling and completion data from more than 1.8 million oil and gas exploratory and development wells came from the Well History Control System (Petroleum Information Corporation, 1986b). These data were incorporated into exploration and development maps that show exploratory penetrations and the areal size of oil and gas pools in a play. In addition, annual and cumulative drilling statistics were developed from this data base. For the majority of the basins assessed, the December 1985 version of the Well History Control System (WHCS) was available. For many of the provinces assessed, the system contained essentially all wells drilled. However, in some provinces, such as parts of the Eastern Interior Region and California, much of the historical record is missing.

Computerized oil and gas field data were available in both the Petroleum Data System (Petroleum Information Corporation, 1986a) and the Significant Oil and Gas Fields of the United States file (NRG Associates, Inc., 1986). Estimated reserves plus cumulative production (known recovery) for fields greater than 1 million BOE were taken from the Significant Oil and Gas Fields file. Published sources, particularly State data, were used for missing fields, primarily for fields in Oklahoma, and to supplement and verify data in the NRG file. Data for sizes of fields in the Appalachian basin were not available. Size and numbers data for fields smaller than 1 million BOE were developed from the National Production System (Petroleum Information Corporation, 1987). Fields in which the known recoveries of gas to oil exceed 20 MCF per barrel were classified

as gas fields. All other fields were classified as oil fields having associated and dissolved gas.

Federal Offshore Regions

The MMS resource estimates were generally based upon data from industry exploration and development operations performed under permits or mineral leases issued for the offshore (OCS) areas of the United States. Since 1954, nearly 9,500 permits have been issued for conducting geophysical or geological studies in the Federal offshore. Additionally, more than 9,000 leases have been issued to private companies for exploration, development, and production of oil and natural gas from the Federal offshore. These permits and leases have resulted in approximately 4 million miles of common depth point (CDP) seismic data and more than 25,000 wells. The MMS has acquired more than 1 million miles of these CDP data and has extensive geological information, including well logs, from offshore wells. This data base was used to identify and map specific prospects within offshore petroleum plays as well as to determine important parameters for the geological and engineering factors that may be associated with these prospects. These data were also used to represent potential prospects that were not identifiable through seismic interpretation or prospects whose size prevented identification because of data gaps or mapping techniques.

In cases where insufficient data were available, data from geologically similar provinces from onshore United States and abroad were used in the assessment. These analogs were identified and developed by MMS experts, and pertinent data were derived from information contained in commercial data bases of oil and natural gas fields maintained on a national and worldwide basis. Data also were obtained from similar petroleum plays in the onshore or State waters through consultation and coordination with USGS resource assessment personnel, particularly in cases where geologic provinces and potential petroleum plays extended across the boundaries of the Agencies' assessments.

ECONOMIC PARAMETERS

The estimates of the undiscovered economically recoverable oil and gas resources were computed by first developing minimum economic field size cutoffs (an estimate of the smallest field that could be developed and have a positive private economic value) and then applying the cutoffs to the field size populations of assessed undiscovered resources thought to be recoverable by conventional production methods. Standard discounted cash-flow analysis was applied in the calculation of minimum economic field sizes, requiring assumptions pertaining to future oil and gas prices, inflation rates, prevailing rates of return and field development costs, infrastructure, and timing. Economic assumptions used in this analysis were developed during the autumn of 1986. In recognition of the uncertainties associated with such assumptions and the different methodologies used by the USGS and MMS in the assessment, the economic parameters were specified in terms of a range of possible outcomes.

During late 1986, the Organization of Petroleum Exporting Countries (OPEC) was attempting to maintain a listed price of $18 per barrel. At about that time, three independent forecasting groups, Data Resources, Inc. (1986), Chase Econometric Associates, Inc. (1986), and the Energy Information Administration of the U.S. Department of Energy (1987b), all forecasted oil price levels of $15 to $20 per barrel from 1987 through 1989. Accordingly, future oil and gas prices were projected by use of initial landed prices of $18 per barrel. Moreover, because of the surplus in natural gas during the mid-1980's, its acquisition price had fallen to about 56 percent of the BTU-equivalent price of oil, so the assumed starting gas price was set at $1.80 per MCF.

Given these starting prices, the assumed growth rates of real oil and gas prices were generated from a restricted range of possible values. During the initial period, from 1987 through 1989, the midpoint growth rate of −3 percent in real oil prices was projected. That is, real oil prices were expected to decline by 3 percent per year. This decline would occur if, for example, the nominal oil prices were stable but the general price level increased by 3 percent per year, as predicted by Data Resources. The midpoint gas price forecast projected a 2 percent per year decline. To allow for uncertainty, the range of price growth rates used in the minimum field size calculations was bounded plus or minus 1 percentage point around the midpoint forecast.

Starting in 1990, greater world demand for oil owing to lower prices, as well as lower oil production from non-OPEC nations, would be expected to result in less OPEC excess capacity, putting upward pressure on oil prices. Therefore, the projected midpoint real oil price growth rate for 1990 and later was set at 4 percent per year. (As the annual inflation rate during this period was set at 6 percent, nominal oil price growth was projected to be about 10 percent per year.) This scenario is equivalent to the projection of Chase Econometrics and slightly below the 6 percent real oil price growth rate estimated by both the Energy Information Administration and Data Resources.

After 1989, the midpoint of the real gas price growth rate was projected to be 5.5 percent. Once again, the oil and gas price growth rates used in the minimum field size calculations were bounded plus or minus 1 percentage point around the midpoint forecast, so a range of real price growth of 3 to 5 percent for oil and 4.5 to 6.5 percent for gas resulted. Envelopes representing projected price levels were computed by use of maximum and minimum real price paths and are shown in figure 8 for oil and in figure 9 for

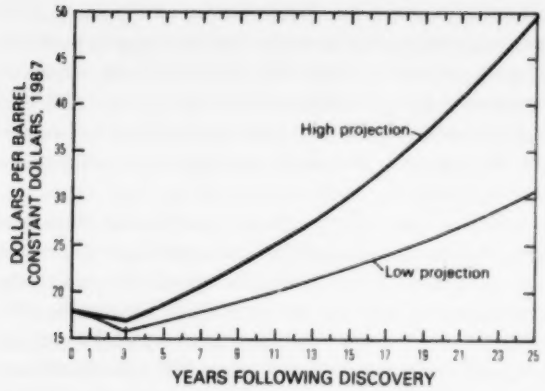


Figure 8. Oil price envelope showing the range of possible price paths. Prices expressed in constant 1987 dollars.

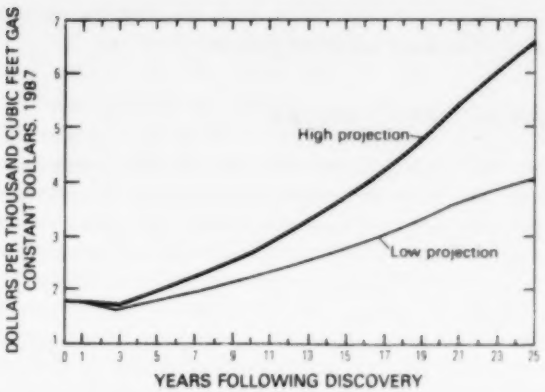


Figure 9. Gas price envelope showing the range of possible price paths. Prices expressed in constant 1987 dollars.

natural gas. For consistency with the historical valuation of gas relative to oil, the absolute price of gas was constrained to be no more than 75 percent of the BTU-equivalent price of oil.

The required rates of return that were used in the cash-flow analysis were assumed to reflect the opportunity cost of capital. An after-tax required return of 8 percent plus or minus 2 percentage points was used. This assumption is consistent with the findings in a number of empirical studies that estimated after-tax returns on OCS leases (see Mead and others, 1980a,b, 1983).

The choice of minimum oil and gas field sizes for specific onshore and State water provinces or Federal offshore prospects was based upon assessed field characteristics and economic assumptions. In the Federal offshore these included parameters affecting costs and rates of production as well as stochastic economic parameters (water depth, estimated porosity, price and rate of return scenarios). For onshore and State waters, the parameters included province location, estimated field depth, and a single price and rate of return scenario within the ranges described above.

The future costs to be incurred by development activities and transportation facilities were based upon costs reported during the 1985–86 period. For the purposes of this assessment, such costs were assumed to remain relatively stable for future activities when viewed in terms of constant (noninflated) dollars. Assumptions about the timing of development activities and the transportation costs were developed specifically for each geologic province on the basis of past experience and current conditions pertaining to each province. Exploration costs were not considered. However, in the exploration process, fields are discovered that cannot support both exploration and development costs, yet some of these fields can be profitably developed, once discovered, and hence add resources to the national reserves. Leasehold and exploration costs, as well as field delineation costs that are incurred prior to the field development decision, were assumed to be sunk and were not used in the discounted cash-flow calculations to determine whether a field was commercially developable.

The economic assumptions and projections used in this assessment to determine minimum commercially developable field sizes are predicated upon a 1987 field discovery and development decision. Furthermore, the field development process is assumed also to have started in 1987. The minimum economic field size (MEFS) represents the smallest field, given the economic conditions postulated here, that would yield a net average after-tax return of 8 percent on the investment required to develop and produce it.

The individual resource assessment methodologies and data bases used by the USGS and the MMS required individual but compatible determinations of MEFS.

METHODS OF ASSESSMENT

The assessments of the undiscovered recoverable oil and gas in each province were based upon review and analysis of each province's petroleum geology and exploration history that incorporated new geologic and geophysical information, several major computer data bases, and more definitive methods of resource appraisal than used in earlier assessments.

The Onshore and State Waters Assessment

The onshore and the coastal State water assessment prepared by the USGS covered 80 petroleum provinces. In these areas, a play-analysis method was employed for accumulations greater than 1 million barrels of oil (MMBO) or 6 BCF of gas. Risk was assigned to the geologic factors

controlling the occurrence of oil or gas, and the size and number of the undiscovered accumulations were estimated.

In the play-analysis method, geologic settings of oil and gas occurrence are modeled. The play is treated as a collection of accumulations conceived as having similar geologic risks and sharing common geologic elements, such as known or suspected trapping conditions, which may be structural, stratigraphic, or a combination of the two. Geologists make judgments as to the probability of occurrence of the geologic factors necessary for the formation of oil or gas accumulations and quantitatively assess accumulation sizes and numbers as probability distributions. The computer package FASPF (Fast Appraisal System for Petroleum-Field Size) then performs the resource calculations on the basis of this information, employing an analytical method based on probability theory, rather than using Monte Carlo simulation (Crovelli, 1987). This arrangement employs the geologist's expertise with geologic factors and the computer's facility in manipulation of numbers within the appraisal model. The method provides for a systematic integration and analysis of the geologic factors essential for the occurrence of oil and gas, a thorough documentation of the analysis, and an assessment containing information on the size, depth distribution and number of hydrocarbon accumulations, and quantity of estimated resources. In this assessment, 250 plays covering the onshore and State offshore areas were identified, and for each play, undiscovered oil and gas resources were estimated. In developing input for the assessment model, several data display and analytical techniques were used. Exploration and development maps were made from the WHCS drilling data base, which showed the dry hole penetrations and the areal boundaries and sizes of oil and gas pools in each play. For most areas these data were plotted by quarter-mile grid cells and thus clearly delineated explored versus unexplored regions of each basin, as well as productive and nonproductive regions. Used in conjunction with geologic maps of the basins showing the structures and stratigraphy relevant to each play, these penetration maps gave the estimators a perception of how much truly prospective area and volume was left to be explored in the play and a perception as to the physical size of the largest field that could conceivably remain to be found in each play.

As a tool to guide the analysis of field-size distributions, we adopted the fitting of a truncated shifted Pareto distribution (shifted to have its origin at 1 million BOE (MMBOE) and truncated by the size of the largest field) to the sizes of the known oil and gas fields in each play. The theory and application of this distribution to the analysis of field sizes is documented by Houghton (1988). The choice of this distribution was based on the fact that it had the requisite J-shape, that it was mathematically simple and tractable, and that it did not have some of the mathematical drawbacks of the more often used log-normal distribution. Essentially, the truncated shifted Pareto could be fitted easily to any sufficiently numerous set of field sizes, and over their range its parameters would quantify both the shape and size of the observed distribution, whether the observed distribution consisted of many small fields of roughly similar size (dispersed habitat) or a more complete range of fields in which the bulk of the contained resource was concentrated in a few of the largest fields (concentrated habitat). Both polar situations, and the full gamut in between, occur in the 250 plays assessed.

For the purposes of guiding the estimators, a truncated shifted Pareto was fitted to the entire set of known fields in each play, and in chronological order of discovery to the first third discovered, to the middle third, and to the last third. This procedure has the advantage of showing in a cogent way, in conjunction with the dates of completion of each third, the discovery history of the play versus field size. Typically, the larger fields in a play are discovered early during the exploration of a play area, with successive discoveries, in general, becoming progressively smaller. By fitting the distribution by chronological segments, the rate of falloff of returns to exploratory effort can be observed. This factor, taken in conjunction with the drilling analysis, is a significant input to prognostication of numbers of undiscovered accumulations in a play. Finally, ratios of associated-dissolved gas to oil and NGL to gas were estimated from historical production data. All of these approximations were used to calculate the probabilistic estimates of oil, gas, and NGL's in accumulations having recoveries equal to or greater than 1 MMBO or 6 BCF of gas.

Probabilistic estimates of recoverable oil and gas in accumulations smaller than these cutoffs were made separately. These estimates were based primarily on log-geometric extrapolations of numbers of fields into field-size classes smaller than the play-analysis cutoffs. Estimates of undiscovered resources for these small fields were made for each province as a whole, rather than by play, and were done in two stages. First, a statistical estimate of the expected discovered plus undiscovered quantity of petroleum in the small fields was made under the assumption that the ratio of the total number of fields (discovered plus undiscovered) in consecutive size classes was the same for any pair of successive size classes (USGS and MMS, 1988, p. 73–80). In view of the above results, a probabilistic range of the undiscovered quantities of oil and gas in small fields was then estimated by expert judgment. These probabilistic estimates were based upon the petroleum geology of the province as well as the density of exploratory drilling and the number of small fields already discovered. The resultant mean estimate of undiscovered resources was then allocated to field-size classes needed for the economic analysis. The final small field-size distributions for undiscovered accumulations were determined for each province by two parameters: the number of fields in the smallest field-size class and the ratio of numbers of fields in

successive classes. These two parameters were determined to satisfy two conditions. The first condition was that the quantity of petroleum in undiscovered small fields equaled the mean previously estimated by expert judgment. The second condition was that the number of fields in large field-size classes (>1 MMBO and 6 BCF of gas) was as close as possible to the number already discovered plus the mean number estimated to be undiscovered.

The economic analysis was performed by use of field and depth distributions estimated in the play analysis and from the small-field assessment.

The estimates for both undiscovered recoverable and economically recoverable resources in each of the 250 onshore and State offshore plays were aggregated by use of probability theory to produce the estimates of total undiscovered resources for the onshore provinces and regions. The same procedure was used to aggregate the onshore and offshore regions to produce estimates for the United States as a whole.

The Federal Offshore Assessment

The MMS resource estimates for the Federal offshore provinces are generally based upon data from industry exploratory and development operations performed under permits or mineral leases issued for the Federal offshore areas of the United States. These data were used by the MMS to identify and map specific prospects within offshore petroleum plays, as well as to determine important parameters for the geologic and engineering factors that may be associated with these prospects. These data also were used for representing potential plays or prospects that are not identifiable through seismic interpretation or prospects whose sizes may be masked by data gaps or mapping techniques.

The MMS developed estimates of undiscovered economically recoverable oil and gas resources by employing a computer mathematical simulation model termed PRESTO (Probabilistic Resource ESTimates-Offshore). This model performs multiple simulations of industry exploratory drilling efforts for these potential prospects and ranks possible outcomes of such efforts, which prove economically successful in terms of resources "discovered" and probabilities of occurrence (USGS and MMS, 1988).

For estimates of the undiscovered recoverable resources, the MMS modified the data base to eliminate the economic constraints imposed upon potential resource "discoveries" and used statistical techniques to extrapolate the size and number of all potential fields within the areas being modeled. For this assessment, MMS defined this category of resources to include potential fields of 1 MMBOE or larger (USGS and MMS, 1988).

Reporting and Calculation Procedures

Both the USGS and the MMS methods provide estimates of resources as a range of values corresponding to probabilities of occurrence in order to express the inherent uncertainty involved in assessment of unknowns. The resulting cumulative probability distributions represent the quantity of undiscovered resources. From these distributions, the low (F_{95}), the high (F_5), and the mean estimates are obtained. To arrive at the estimated quantity of undiscovered resources for larger areas, such as provinces, regions, or the Nation, distributions for the basic assessment units were progressively aggregated, with geologic dependency incorporated at each level. For the onshore and State water assessments, the plays within provinces were considered to be fully dependent. For the aggregation of provinces into regions, the provinces within each region were assigned a 50-percent dependency. In the aggregation of regions, all regions, both onshore and offshore, were considered to be completely independent.

RESULTS

The assessed undiscovered *recoverable* conventional oil and gas resources for the United States are estimated to range from 33 to 70 BBO and from 307 to 507 TCF of gas, corresponding to the 95-percent and 5-percent probability levels, respectively (table 2). Corresponding estimates for NGL are 6 to 12 BB. The assessed undiscovered *economically recoverable* oil and gas resources for the United States are estimated to range from 21 to 54 BBO and from 208 to 326 TCF of gas, corresponding to the 95-percent and 5-percent probability levels, respectively (table 2). Corresponding estimates for NGL are 5 to 8 BB.

Figures 10 and 11 show the estimated cumulative probability distributions of undiscovered recoverable resources for crude oil and natural gas; also shown at the same scale are the discovered volumes (cumulative production and reserves). Measured (proved) reserves at the time of the assessment were 29.5 BBO and 206.6 TCF of natural gas. On the basis of mean values, undiscovered recoverable resources of crude oil are assessed to be about 67 percent larger than measured reserves; undiscovered resources of natural gas are assessed to be 93 percent larger than measured reserves. Further, it is estimated that an additional 22 BBO (indicated and inferred reserves) and 99 TCF of gas (inferred reserves) will be added to reserves through growth of known fields.

Figures 12 and 13 illustrate, by use of mean values, the distribution, both onshore and offshore (Federal and State waters), of the estimated undiscovered recoverable resources between the lower 48 States and Alaska for crude oil and for natural gas, respectively. As shown on those figures, 34 percent of the estimated undiscovered recover-

Table 2. Conventional oil and natural gas resources by region

[Oil in billion barrels; gas in trillion cubic feet; natural gas liquids (NGL) in billion barrels. NGL shown only in totals. *, indicated reserves are includedwith measured reserves estimated by the Minerals Management Service. +, not known. Mean value totals may not be equal to the sums of the constituent means because numbers have been independently rounded. Fractile values (F_{95}, F_5) are not additive. Gas includes both nonassociated and associated-dissolved gas. F_{95} represents a 19 in 20 chance and F_5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated]

Region		Produced resources (Cumulative production)	Reserves		Undiscovered recoverable resources			Undiscoverered economically recoverable resources		
			Measured	Inferred and indicated	F_{95}	Mean	F_5	F_{95}	Mean	F_5
Onshore and State waters										
1	Oil	6.1	6.9	6.4	3.6	13.2	31.3	1.1	7.9	23.8
	Gas	3.8	32.7	3.0	15.6	57.9	138.6	0.2	1.2	3.7
2	Oil	20.3	4.7	1.2	1.5	3.5	6.6	1.4	3.4	6.5
	Gas	33.2	3.9	2.6	5.5	11.0	19.1	5.1	10.6	18.8
3	Oil	3.1	.6	.4	.5	1.5	3.4	.4	1.5	3.3
	Gas	24.7	17.1	4.9	9.6	21.3	39.3	9.4	21.0	38.9
4	Oil	7.1	1.2	1.3	2.7	4.5	6.9	2.2	3.8	6.0
	Gas	13.1	7.6	3.6	7.0	15.2	27.8	6.2	14.2	26.5
5	Oil	30.2	5.4	3.8	1.5	2.6	4.0	1.4	2.4	3.8
	Gas	82.2	16.7	12.9	11.9	20.1	31.3	11.2	19.3	30.3
6	Oil	43.1	3.7	5.7	2.4	4.2	6.7	2.2	4.0	6.5
	Gas	285.6	33.6	42.3	51.2	82.5	123.6	47.7	79.3	121.6
7	Oil	17.3	1.1	1.4	1.2	1.9	2.7	1.1	1.7	2.5
	Gas	145.4	37.5	18.3	16.2	28.7	46.0	15.0	26.8	43.1
8	Oil	8.4	.5	.7	1.3	1.8	2.4	1.3	1.8	2.4
	Gas	33.9	8.2	5.0	10.8	17.2	25.7	10.1	16.3	24.5
9	Oil	.1	< .1	< .1	.1	.2	.5	.1	.2	.5
	Gas	< .1	< .1	< .1	< .1	< .1	< .1	0.0	< .1	< .1
Total onshore and State waters										
	Oil	135.6	24.2	21.1	19.6	33.3	51.9	13.9	26.6	45.0
	Gas	622.0	157.4	92.7	178.7	254.0	346.7	145.6	188.7	239.1
	NGL	+	+	3.8	5.0	6.8	9.0	4.0	5.5	7.4
Federal Offshore										
1A	Oil	0.0	0.0	0.0	.6	3.4	9.4	0.0	.9	4.8
	Gas	0.0	0.0	0.0	4.7	16.8	39.4	0.0	0.0	0.0
2A	Oil	.4	1.3	.2*	.9	3.4	8.3	.4	2.0	5.5
	Gas	.3	2.1	.3*	3.5	8.0	15.1	1.8	5.2	11.0
6A	Oil	6.9	4.0	.4*	4.9	8.6	13.6	2.6	5.0	8.6
	Gas	75.2	47.0	5.8*	63.0	103.3	156.9	36.0	64.3	103.7
9A	Oil	0.0	0.0	0.0	.1	.7	2.3	0.0	.2	.8
	Gas	0.0	0.0	0.0	6.8	17.0	33.7	0.0	4.5	9.8
Total Federal offshore										
	Oil	7.3	5.3	.6*	9.2	16.1	25.6	4.0	8.2	14.3
	Gas	75.5	49.2	6.1*	97.8	145.1	204.8	44.3	74.0	113.8
	NGL	+	+	.2	.6	1.8	3.8	.2	.8	1.8
Total United States										
	Oil	142.9	29.5	21.7	33.2	49.4	69.9	20.7	34.8	53.8
	Gas	697.5	206.6	98.8	306.8	399.1	507.2	208.2	262.7	325.5
	NGL	24.4	8.2	4.0	6.1	8.6	11.5	4.6	6.3	8.4

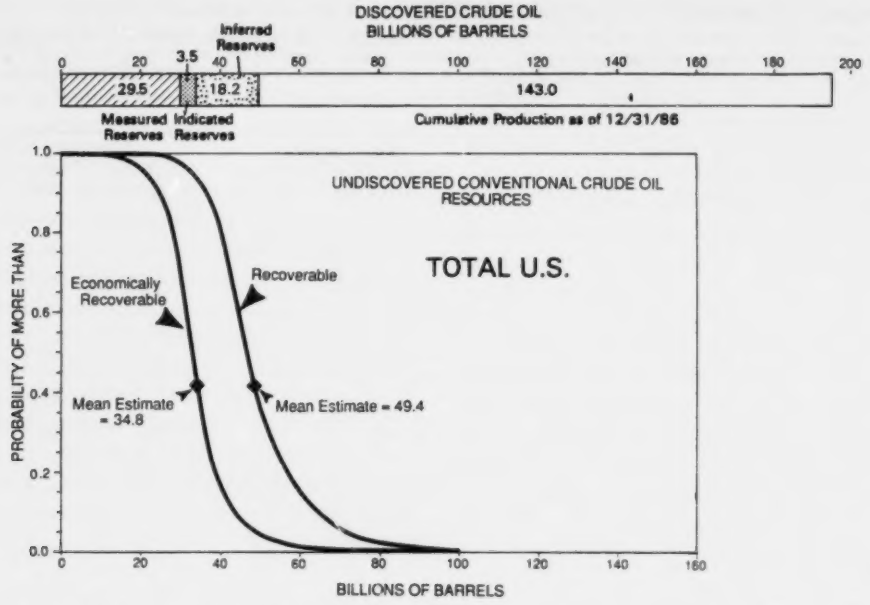


Figure 10. Discovered crude oil and cumulative probability distributions for undiscovered recoverable and undiscovered economically recoverable conventional crude oil resources of the United States.

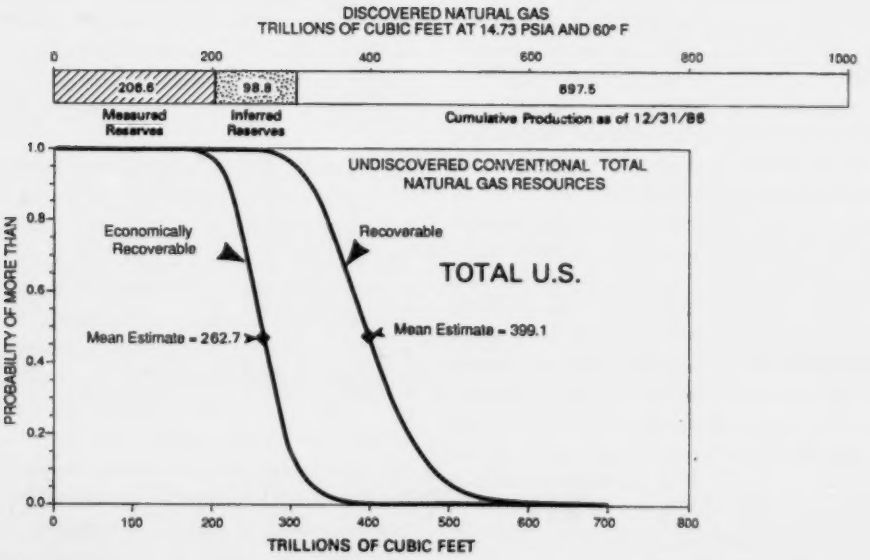


Figure 11. Discovered natural gas and cumulative probability distributions for undiscovered recoverable and undiscovered economically recoverable conventional natural gas resources of the United States.

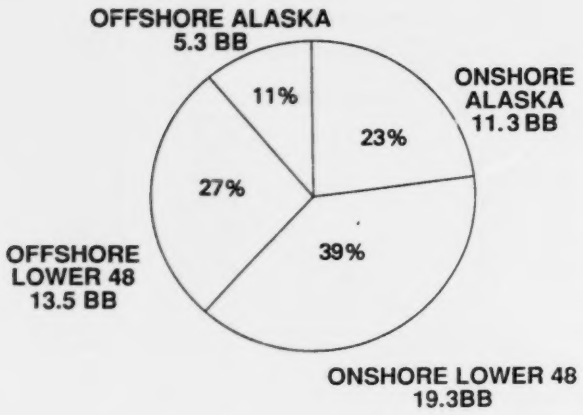


Figure 12. Distribution of undiscovered recoverable conventional crude oil resources based on mean estimates. Offshore estimates here include both Federal and State waters. Units in billions of barrels.

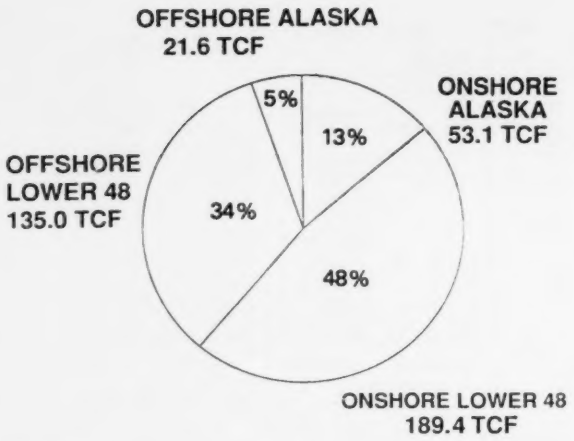


Figure 13. Distribution of undiscovered recoverable conventional total natural gas resources based on mean estimates. Offshore estimates here include both Federal and State waters. Units in trillions of cubic feet.

able crude oil resources and 18 percent of the assessed undiscovered recoverable natural gas resources occur in Alaska. Approximately 62 percent of the estimated undiscovered recoverable crude oil resources and 61 percent of the estimated undiscovered recoverable natural gas resources are onshore.

As reported in table 2, the estimates of economically recoverable resources approach recoverable quantities in all areas except Alaska and the offshore, where large accumulations are required for economic development. Considering the mean values, 70 percent of the estimated undiscovered recoverable crude oil and 66 percent of the natural gas overall are estimated to be economically recoverable for the United States. The major areas where the estimates are significantly constrained by economics are in Alaska and, to a lesser extent, the offshore areas of the lower 48 States (figs. 14 and 15). Practically none of the undiscovered gas resources in Alaska are classified as economically recoverable, primarily because of remoteness from markets and lack of transportation facilities. Pipelines may eventually be constructed to transport natural gas from northern Alaska or the gas may be used in the thermal recovery of heavy oil resources known to exist there.

The assessment of the United States undiscovered recoverable petroleum potential, for essentially the same resource categories, is decreased from that estimated in 1980 (Dolton and others, 1981) as shown in table 3.

Much of the overall decline in estimates of undiscovered resources, both onshore and offshore, is due to reevaluations reflecting new geological data from exploration drilling in several major regions expected to have petroleum potential. The expected major discoveries were not forthcoming in the frontier exploration areas of Alaska and Atlantic offshore nor in the overthrust belt of the Western United States. Moreover, most other onshore regions did not meet expectations of resource occurrence that were postulated earlier, although in a few areas estimates have increased. The massive exploration effort of industry of the late 1970's and early 1980's simply did not confirm some of the geological expectations for large new accumulations included in the earlier estimates. Furthermore, almost every onshore play having sufficient data showed a decline in sizes of fields discovered over the history of the play. An example of this field-size decline is shown in figure 16.

Change in the estimates also result from different assumptions, methods, and data that were used in the two studies. Circular 860 assessors employed a direct assessment technique to estimate undiscovered resources at a province level, whereas in this study assessors employed a play-level analysis. The methods used in this study had more specific and detailed data requirements. In the Federal offshore, detailed proprietary seismic data were used in the analysis of prospects, whereas in Circular 860, broadly spaced regional seismic data supported province estimates. For the onshore assessments in this study, the play-analysis approach required more direct use of exploratory drilling data and field-size data from known fields. Field data that were available for this study were not available for the Circular 860 analysis.

Important differences in assumptions about future prices of commodities and technology changes also certainly influenced the results of the two studies. When the 1980 estimates were made, world oil prices exceeded $30 per barrel and were increasing rapidly. At the time of this study, world oil prices were about $18 per barrel. Circular 860 assessors considered continued development and application of new technology but did not specify what recovery

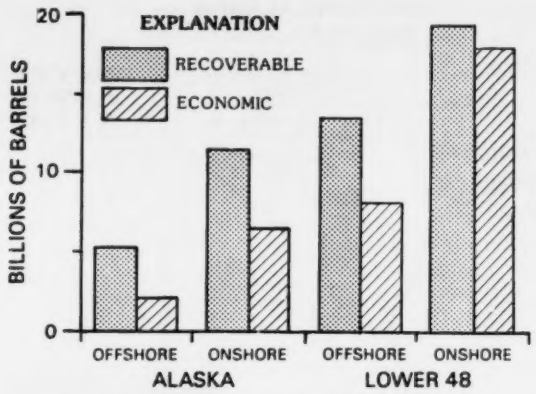


Figure 14. Comparison of mean estimates of undiscovered recoverable oil resources and undiscovered economically recoverable oil resources for Alaska and the lower 48 States.

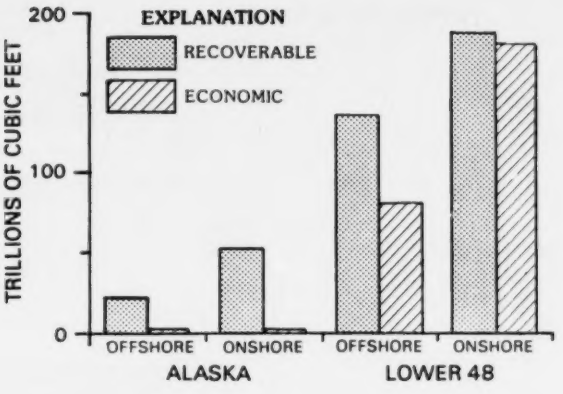


Figure 15. Comparison of mean estimates of undiscovered recoverable natural gas resources and undiscovered economically recoverable natural gas resources for Alaska and the lower 48 States.

Table 3. Comparison of 1981 and 1987 estimates of total conventional oil and gas resources for the onshore and offshore United States

[Figures in billions of barrels of oil and trillions of cubic feet of gas. Gas includes both nonassociated and associated-dissolved gas]

	Assessment year	Cumulative production	Identified resources[1]	Undiscovered recoverable (mean estimate)	Total
Oil					
Circular 860 (1981)	1980	120.7	54.8	82.6	258.1
This study	1987	143.0	51.2		
Recoverable				49.4	243.6
Economically recoverable				34.8	229.0
Gas					
Circular 860 (1981)	1980	578.0	369.0	593.8	1,540.8
This study	1987	697.5	305.4		
Recoverable				399.1	1,402.0
Economically recoverable				262.7	1,265.6

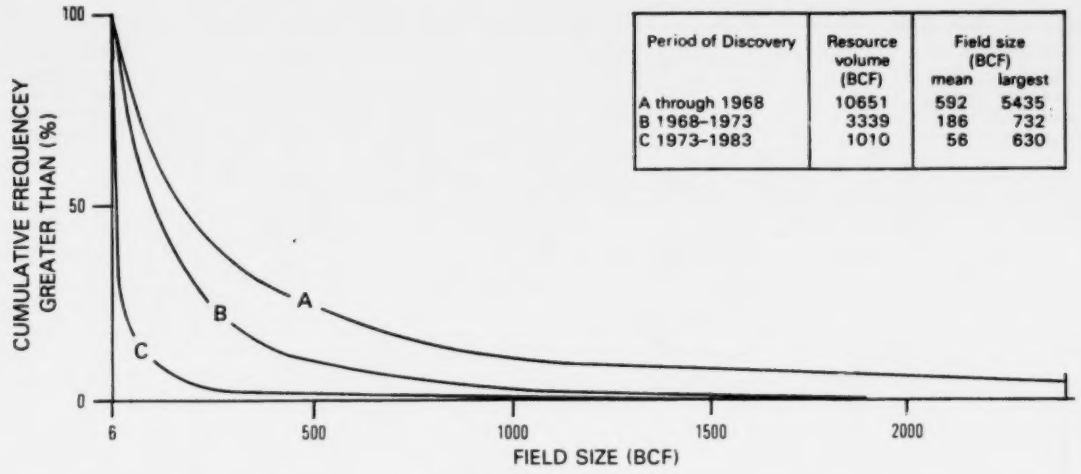
[1] Identified resources are the sum of measured, indicated and inferred reserves. Adjustment to measured and inferred reserves between 1980 and this study occurred because a different growth function was used to calculate inferred reserves and reserve estimates came from different sources.

efficiencies might be expected in the future. This study, on the other hand, was based on current recovery efficiency. The intent of this study was not to deny the importance of those kinds of changes but to present estimates that reflect current production practices. Should improvements occur in recovery efficiencies from conventional reservoirs, exceeding historical growth, additional volumes of oil and gas would accrue to the undiscovered recoverable resources estimated in this study.

Another factor affecting the comparison of these estimates of undiscovered resources is the interim discovery of oil and gas. A rough estimate of the oil and gas discovered in 1980 through 1986, including projected growth of these new discoveries, is 6 to 8 BBO and 60 to 70 TCF of gas. These new discoveries cause a shift of resources from the undiscovered to the identified or discovered category.

With respect to the MMS assessment of 1984 (Cooke, 1985), the estimates for the undiscovered *economically recoverable* oil resources for the Federal offshore area are compared in table 4. The 1984 assessment by MMS did not present estimates for undiscovered recoverable resources but presented estimates only for the undiscovered economically recoverable resources.

Comparison of the estimates presented here with estimates from other sources reveals a general concurrence about the magnitude of undiscovered conventional recoverable resources for the United States (figs. 17 and 18). A



Period of Discovery	Resource volume (BCF)	Field size (BCF) mean	largest
A through 1968	10651	592	5435
B 1968–1973	3339	186	732
C 1973–1983	1010	56	630

Figure 16. An example of the change in size of fields discovered through time in the Lower Paleozoic gas play, Permian basin, Texas and New Mexico. Field size in billions of cubic feet of gas (BCF). Data are for fields greater than 6 BCF. Curve A, cumulative field-size distribution, discoveries through 1968; Curve B, discoveries 1968–73; Curve C, discoveries 1973–83.

significant difference, however, exists between estimates presented here and the Potential Gas Committee's 1987 estimates shown on figure 18. As discussed by Fisher and others (1988), much of the difference can be explained by the fact that definitionally the Potential Gas Committee's (Potential Gas Committee, 1987) estimates include resources from low-permeability "tight" sandstones (Potential Gas Committee, 1983) and fractured shales; these were excluded from the estimates of conventional resources assessed in this study.

The regional distribution of conventional petroleum resources is shown by figures 19 and 20, depicting for oil and gas, respectively, undiscovered recoverable quantities, reserves, and cumulative production. The exploration maturity of the onshore regions is obvious compared to the offshore. The relative importance of the Gulf Coast, the Gulf of Mexico, and Alaska for undiscovered recoverable gas and of Alaska and the Gulf of Mexico for undiscovered recoverable oil are also evident.

Figures 21 and 22 illustrate the cumulative probability curves for undiscovered oil and gas resources onshore and in State waters. Figures 23 and 24 display similar cumulative curves for the Federal offshore undiscovered oil and gas resources. Comparison of the curves for undiscovered economically recoverable resources and undiscovered recoverable resources on the same graph points out the effect of imposing economic constraints on the resources estimated. The percentage difference, or spread, between the estimates of undiscovered economically recoverable and undiscovered recoverable is greater for the offshore than onshore and reflects higher development costs and technological constraints associated with marine operations, particularly in deep water and harsh operating environments.

The onshore small fields (fields having less than 1 million BOE recoverable hydrocarbons) account for about 94 percent of the estimated number of undiscovered fields in the lower 48 States. Small fields based on mean values are expected to contain about 25 percent of the total undiscovered oil and about 13 percent of the total undiscovered gas. For the onshore lower 48 States, about 52 percent of the undiscovered small oil fields and 46 percent of the small gas fields were estimated to be commercially developable. None of the undiscovered small fields in the State offshore were estimated to be commercially developable. It is estimated that 73 percent of the total hydrocarbons in undiscovered small oil fields and 66 percent of the hydrocarbons in small undiscovered nonassociated gas fields were commercially developable. Exploration costs, which were not built into the economic analysis, would, nevertheless, control exploration for these small-field resources.

The highest concentrations of undiscovered small oil fields are in the Rocky Mountains and Northern Great Plains (Region 4) and in the Mid-Continent (Region 7), whereas the Gulf Coast (Region 6) and the Mid-Continent have the highest number of small gas fields. Because most of the fields assessed in the Eastern United States (Regions 8 and 9) are expected to be shallow, these regions contain the highest proportion of small fields that are expected to be commercially developable.

The estimated mean undiscovered recoverable oil resources are two-thirds larger than measured reserves, and

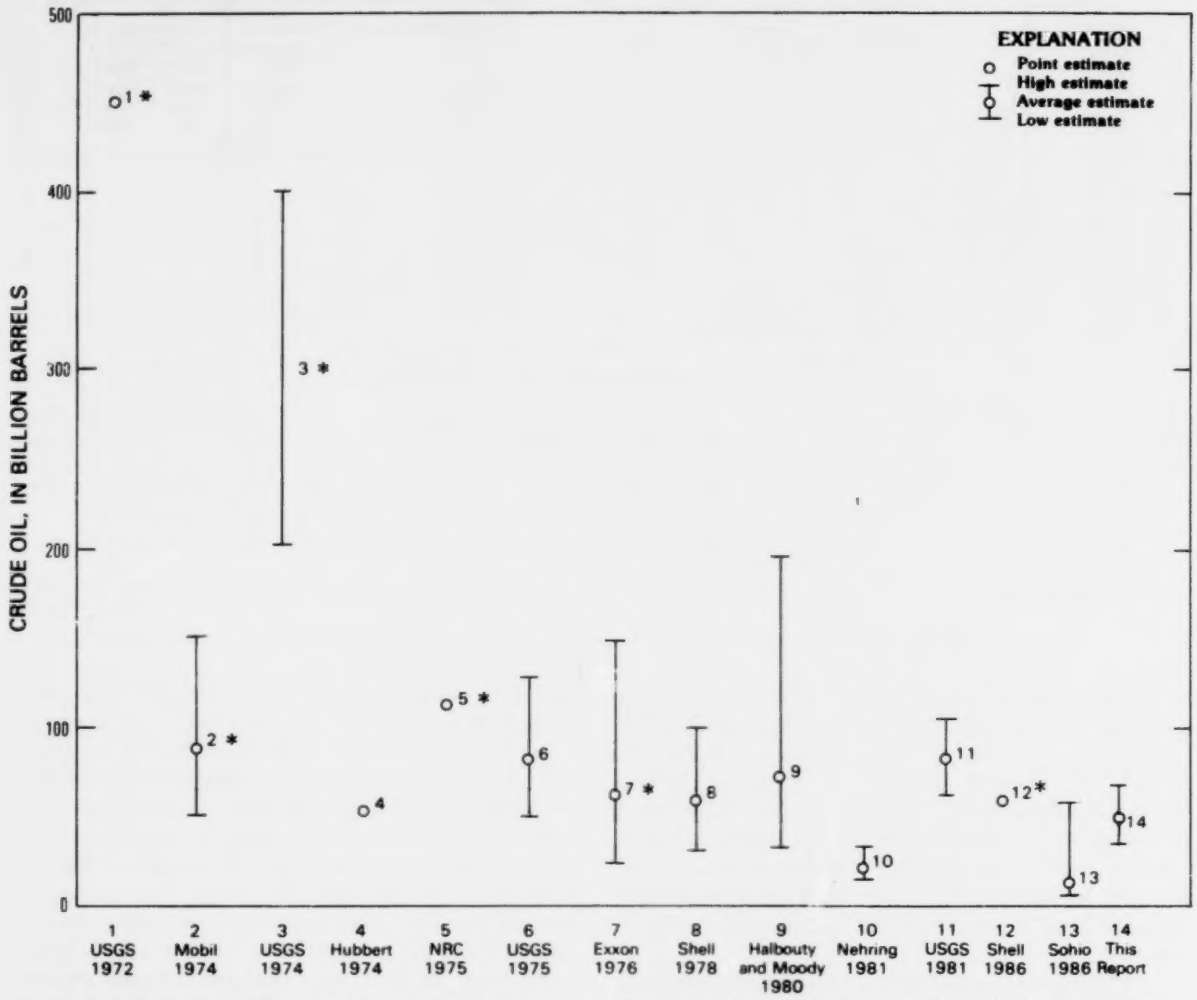


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Figure 17. Comparison of selected estimates of undiscovered recoverable conventional oil resources for the United States. Estimates are not always directly comparable because of different areas and commodities assessed. Asterisk indicates estimates that include natural gas liquids.

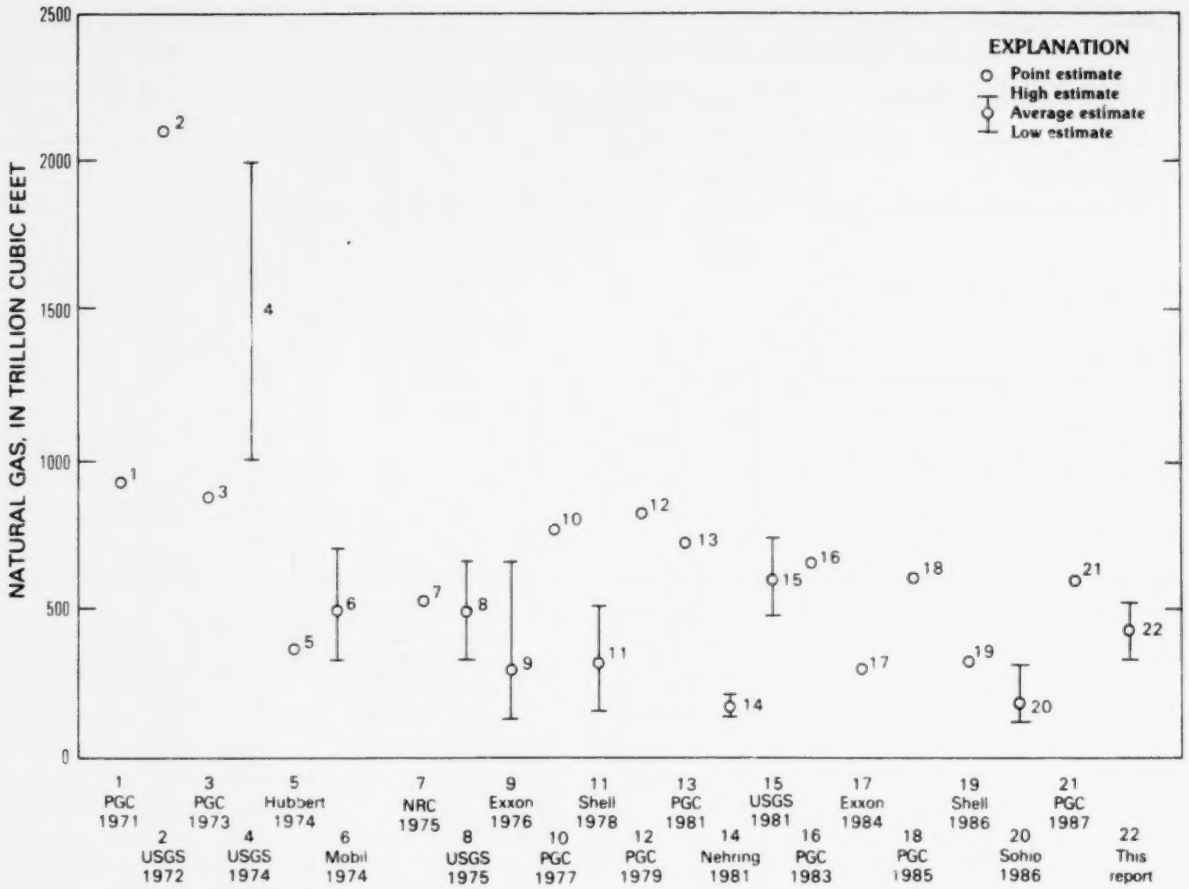

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Figure 18. Comparison of selected estimates of undiscovered recoverable conventional natural gas resources for the United States. Estimates are not always directly comparable because of different areas and commodities assessed.

Table 4. Comparison of 1984 and 1987 estimates of total conventional oil and gas resources for the Federal offshore

[Figures in billions of barrels of oil and trillions of cubic feet of gas. Gas includes both nonassociated and associated-dissolved gas]

	Assessment year	Cumulative production	Identified resources	Undiscovered recoverable (mean estimate)	Total
Oil and liquids					
MMS 85-0012					
Economically recoverable (1985)	1984	6.2	4.6	12.2	23.0
This study	1987	7.3	5.9		
Recoverable				16.1	29.3
Economically recoverable				8.2	21.4
Gas					
MMS 85-0012					
Economically recoverable (1985)	1984	62.7	45.8	90.5	198.5
This study	1987	75.5	55.3		
Recoverable				145.1	275.9
Economically recoverable				74.0	204.8

measured reserves are about 10 times the 1987 annual domestic production rate. The potential for large accumulations is primarily in Alaska and in the Federal offshore areas, where long lead times are required for development and for delivery of commodities to market. In contrast, the large numbers of relatively small oil accumulations, which typify onshore areas of the lower 48 States, are readily accessible to markets. In consideration of this geographic distribution of oil resources and the discovery rates experienced over the last decade (approximately 1 BBO per year), it is likely that annual additions to oil reserves from discoveries of conventional resources will decline over the next decade at current reduced levels of exploratory drilling.

In the case of natural gas, the estimated mean undiscovered recoverable resources are nearly double the measured reserves, and measured reserves (excluding northern Alaskan reserves) are about 10 times the 1987 annual domestic production rate. The large estimated gas resources on the North Slope of Alaska are not economic, given the assumptions specified in this assessment. About 81 percent of the Nation's estimated undiscovered recoverable gas resources are located in the lower 48 States, both onshore and offshore, where they are accessible for exploration. Provided there are adequate incentives for gas exploration and development, the large measured and inferred reserves of natural gas and the assessed distribution of undiscovered recoverable gas resources suggest that the availability of gas resources should not limit our ability to sustain current gas production rates for several years.

In this study, unconventional resources of low-permeability "tight" gas-bearing sandstones and gas-bearing fractured shales, which are now largely identified occurrences, rather than being undiscovered, were separated geologically and excluded. Some conventional gas resources likely are embedded in these unconventional reservoir sequences, where geologic data were inadequate to permit their separation.

National-scale estimates of resources in low-permeability "tight" reservoirs have been published by the National Petroleum Council (1980), Potential Gas Committee (1983), and Fisher and others (1988). According to these and other studies, the United States has unconventional resources of gas that are estimated to be large in comparison to conventional resources. These resources include not only the "tight" and fracture reservoirs cited above, but also coal bed methane, gas hydrates, and other sources. Some gas is now produced from these sources. Improved economic incentives and new technologies could accelerate their development and influence long-term energy supply estimates.

CONCLUSION

The last Government assessment of the undiscovered recoverable conventional oil and gas resources for the United States was released in 1981. Since that time, many changes have occurred that affect the long-term energy picture. Updated estimates of the Nation's undiscovered oil and gas resources were needed for planning purposes.

In response to that need, two agencies of the Department of the Interior cooperated in a systematic assessment of conventional resources. More extensive data bases, knowledge from recent exploratory and development drilling, combined with more sophisticated computer and geologic modeling techniques, were used. Economic assumptions were made to estimate undiscovered resources that would be economic to produce, given those assumptions. To indicate long-term potential, additional estimates were made without economic constraints but assuming conventional recovery techniques.

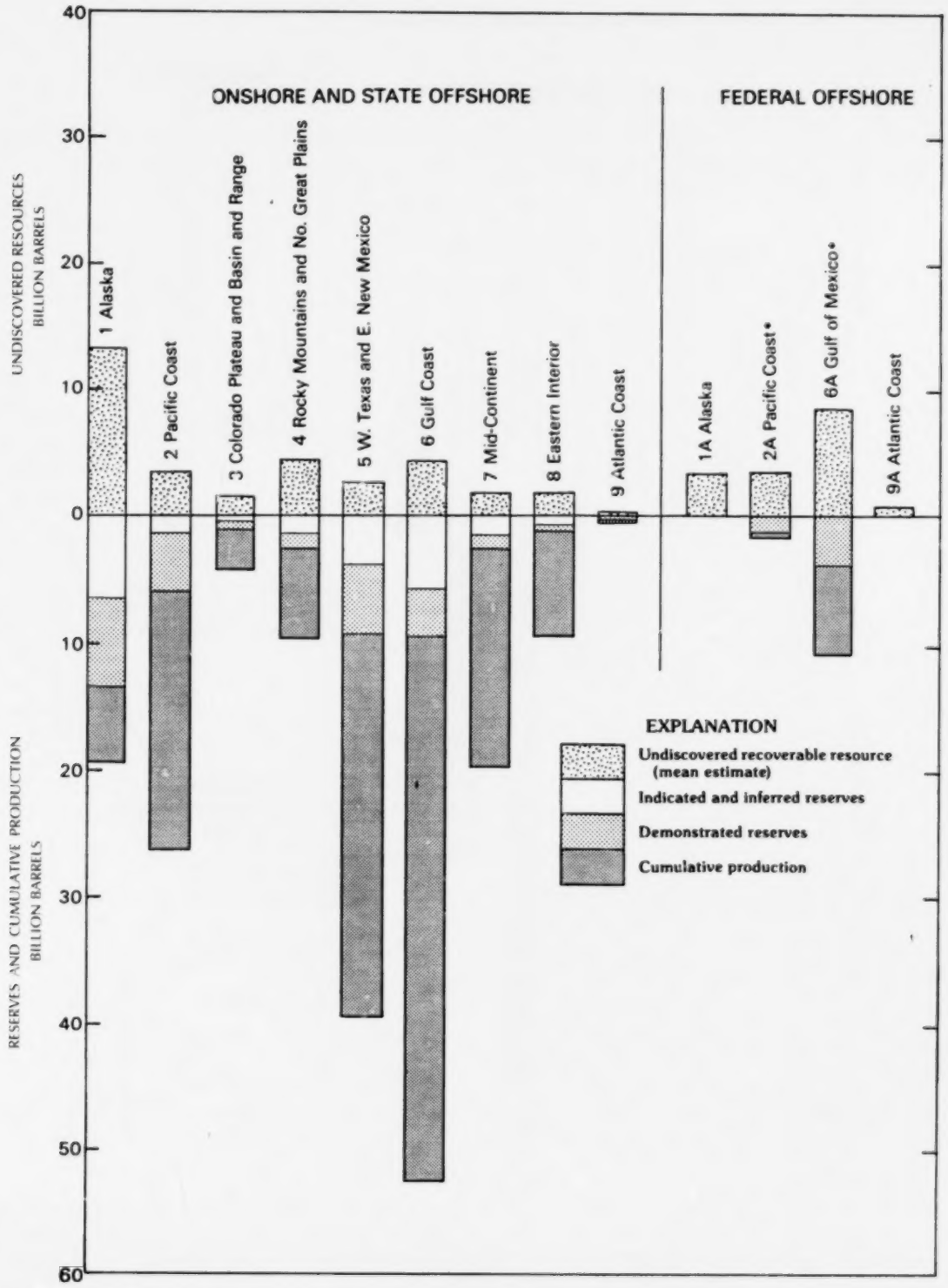

Figure 19. Estimates of discovered amounts (cumulative production and reserves) and undiscovered recoverable amounts (mean estimates) of crude oil in billions of barrels by region. Asterisk indicates that demonstrated, indicated, and inferred reserves are combined.

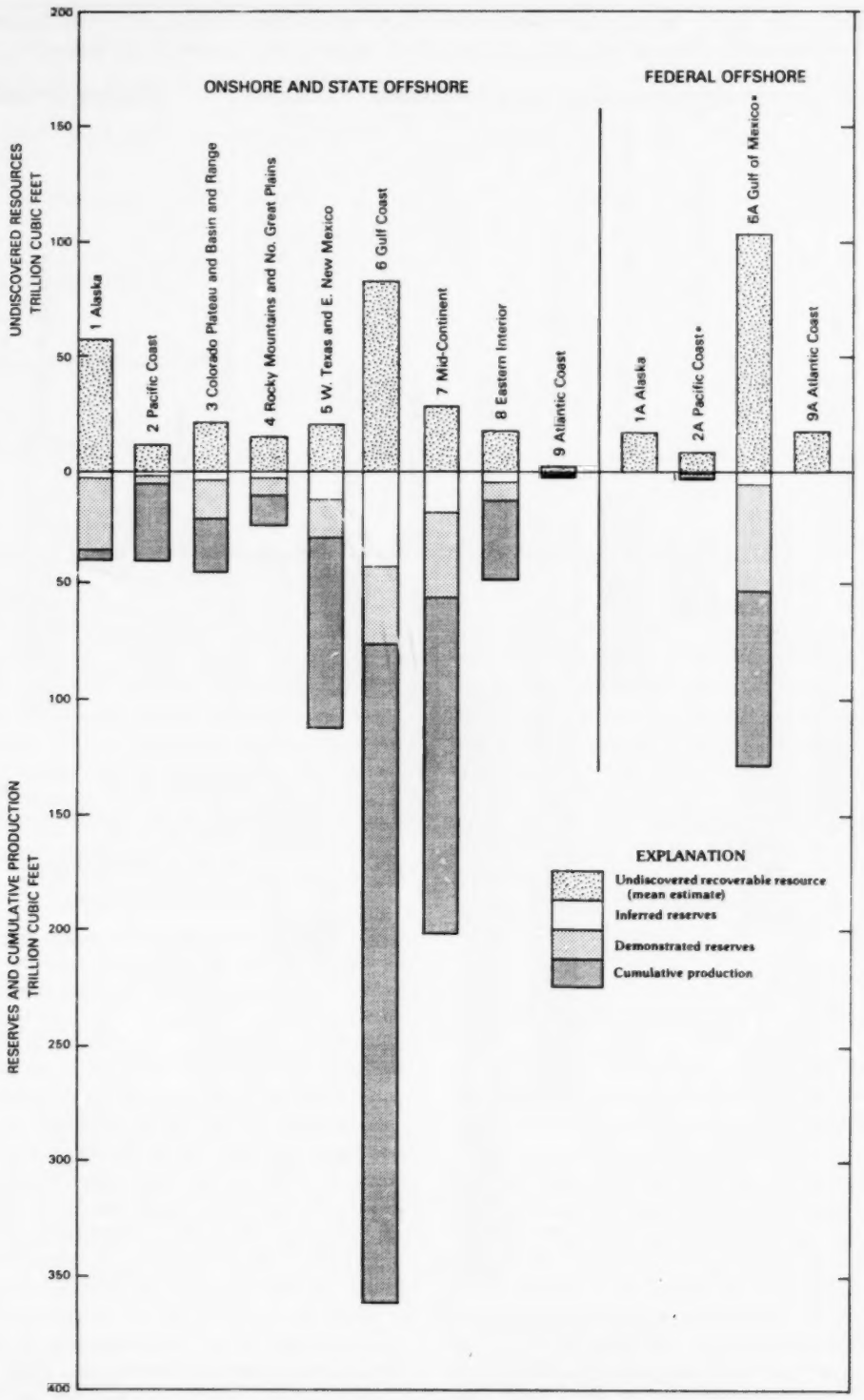

Figure 20. Estimates of discovered amounts (cumulative production and reserves) and undiscovered recoverable amounts (mean estimates) of natural gas in trillions of cubic feet by region. Asterisk indicates that demonstrated and inferred reserves are combined.

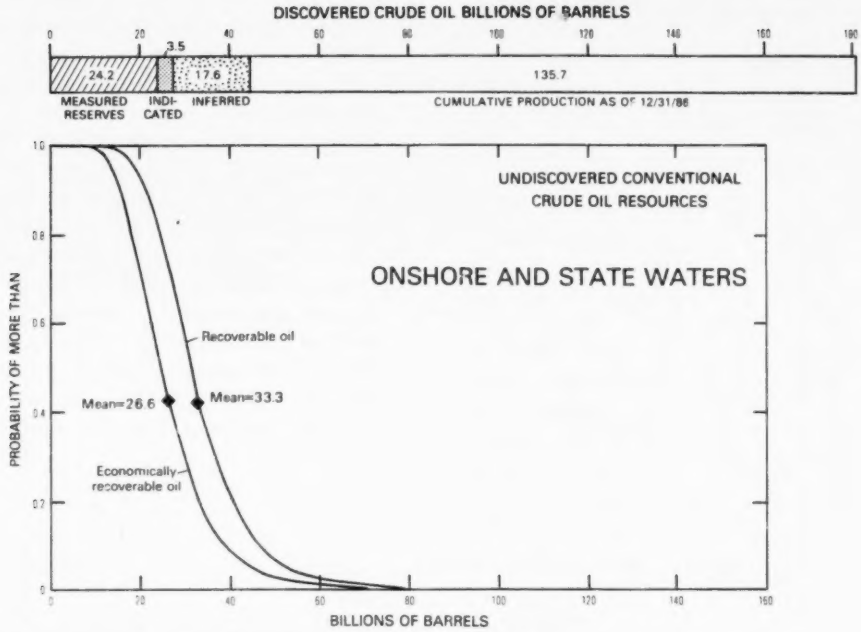

Figure 21. Cumulative probability distributions for estimates of undiscovered recoverable and undiscovered economically recoverable crude oil resources, onshore and State waters, United States.

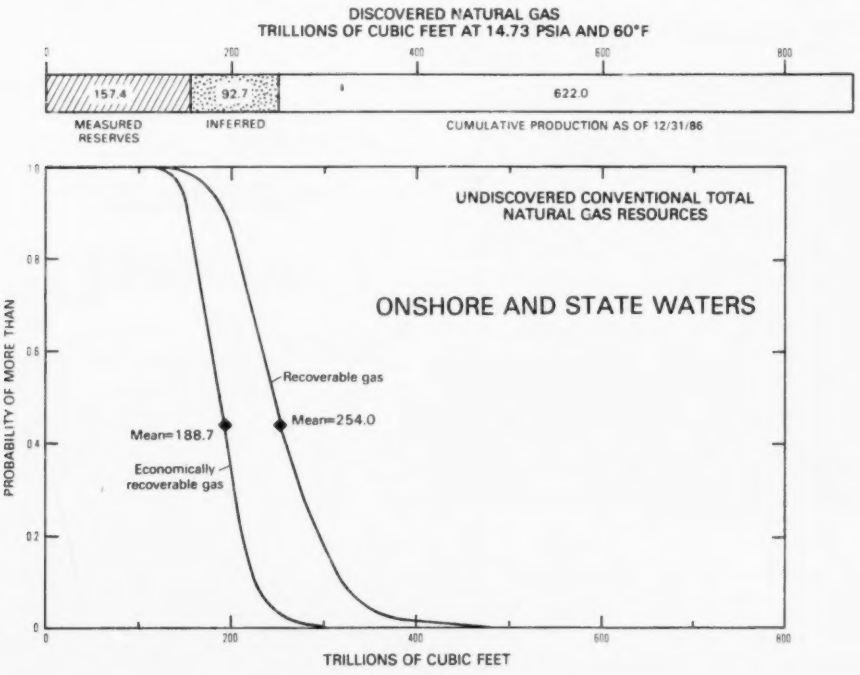

Figure 22. Cumulative probability distributions for estimates of undiscovered recoverable and undiscovered economically recoverable natural gas resources, onshore and State waters, United States.

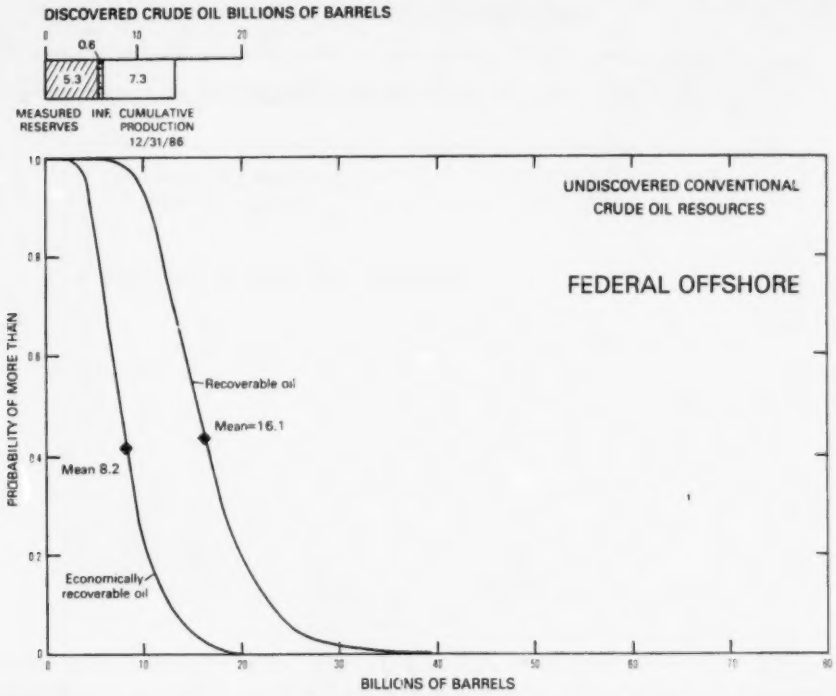

Figure 23. Cumulative probability distributions for estimates of undiscovered recoverable and undiscovered economically recoverable crude oil resources, Federal offshore United States. INF, inferred reserves.

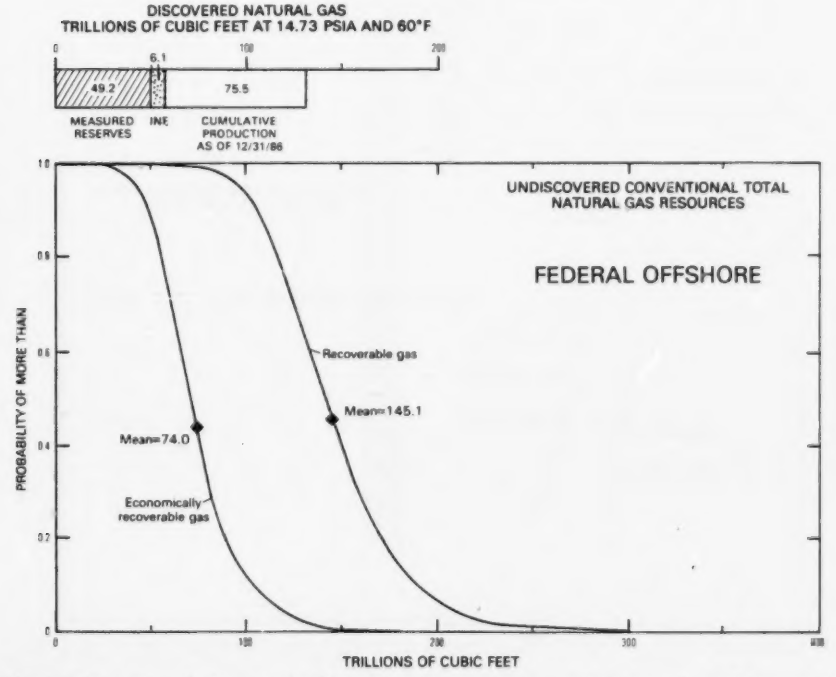

Figure 24. Cumulative probability distributions for estimates of undiscovered recoverable and undiscovered economically recoverable natural gas resources, Federal offshore United States. INF, inferred reserves.

The mean of the distribution of possible values for the undiscovered economically recoverable conventional petroleum resources (oil, natural gas, and NGL) is 88 BBOE, and the mean of the undiscovered recoverable resources is 125 BBOE. On the basis of barrels of oil equivalent, approximately one-fourth of the undiscovered economically recoverable resources and one-third of the undiscovered recoverable resources are estimated to be in the Federal offshore. These estimates are lower than previous estimates but show that significant conventional oil and gas resources remain to be discovered. Additions also can be expected from future enhanced recovery techniques and practices, which would increase recovery efficiencies beyond those used in this assessment. Additions attributable to other "unconventional" resources, which are largely dependent upon increased price and future technologic advances, are not estimated.

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Assessment of the Federal Offshore Waters

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APPENDIX A: UNDISCOVERED CONVENTIONAL OIL, GAS, AND NATURAL GAS LIQUIDS RESOURCES BY GEOLOGIC PROVINCE

This section presents the estimates of undiscovered recoverable and economically recoverable conventional oil, gas, and natural gas liquids resources for the onshore and offshore geologic provinces of the United States. Figures A1 and A2 show the province boundaries for the lower 48 States and Alaska areas, respectively. The province numbers on the maps correspond to those in tables A1 through A4, which list estimates of *undiscovered recoverable* and *economically recoverable* conventional oil, gas, and natural gas liquids for onshore provinces and adjacent State waters of the United States and estimates of undiscovered recoverable and economically recoverable oil and gas for Federal offshore provinces of the United States.

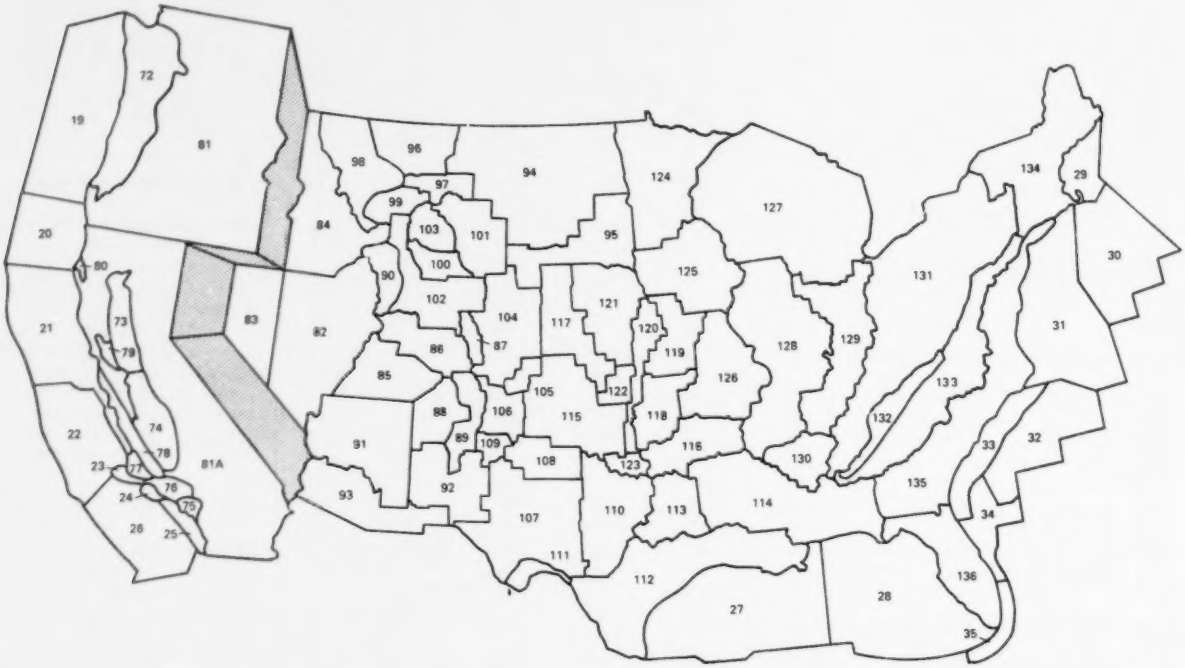

Figure A1. Index map of lower 48 States showing provinces assessed. Names of provinces are listed by number in tables A1 and A2.

Figure A2. Index map of Alaska showing provinces assessed. Names of provinces are listed by number in tables A1 and A2.

Table A1. Estimates of undiscovered recoverable conventional oil, gas, and natural gas liquids (NGL) in onshore provinces and adjacent State waters of the United States

[Mean value totals may not be equal to the sums of the component means given elsewhere because numbers have been independently rounded. Fractile values (F_{95}- F_5) are not additive. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity; —, no estimate. F_{95} represents a 19 in 20 chance and F_5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated]

		Crude oil (billion barrels)			Gas (trillion cubic feet)			NGL (billion barrels)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
Region 1--Alaska										
058	Arctic Coastal Plain	1.50	14.80	6.00	4.66	58.24	22.11	0.13	1.41	0.56
059	Northern Foothills	.67	5.12	2.24	4.03	24.31	11.49	.07	.44	.21
060	Southern Foothills	.58	13.18	4.35	2.85	61.56	20.49	.04	.87	.29
061	Kandik	.00	.49	.11	.00	.49	.11	.00	.00	.00
062	Alaska Interior	.00	.00	.00	.45	2.85	1.33	.00	Negl.	Negl.
063	Interior Lowlands (incl. in 062)									
064	Bristol basin	.00	.00	.00	.11	.67	.32	.00	.00	.00
065	Hope basin	–	–	–	–	–	–	–	–	–
066	Copper River (incl. in 062)									
067	Cook Inlet	.09	.64	.29	.35	3.91	1.53	.00	Negl.	Negl.
068	Alaska Peninsula (Incl. in 062)									
069	Gulf of Alaska	.03	.58	.19	.03	2.00	.56	Negl.	.01	Negl.
070	Kodiak	–	–	–	–	–	–	–	–	–
071	Southeastern Alaska	–	–	–	–	–	–	–	–	–
Region 2--Pacific Coast										
072	Western Oregon-Washington	0.00	0.00	0.00	0.87	4.29	2.18	0.00	0.00	0.00
073	Sacramento basin	.00	.00	.00	.76	3.37	1.78	Negl.	Negl.	Negl.
074	San Joaquin basin	.55	3.22	1.53	1.23	6.69	3.27	.08	.53	.24
075	Los Angeles basin	.24	1.42	.68	.29	1.69	.81	.02	.09	.04
076	Ventura basin	.20	1.63	.70	.40	2.93	1.30	.02	.12	.05
077	Santa Maria basin	.13	.49	.27	.11	.44	.24	.01	.02	.01
078	Central Coastal	.05	.72	.27	.04	.58	.21	Negl.	.02	.01
079	Sonoma-Livermore basin	.00	.01	.01	.00	.01	.01	.00	.00	.00
080	Humboldt basin	.00	.00	.00	.01	.10	.04	.00	.00	.00
081	Eastern Oregon-Washington	.00	.00	.00	.43	2.39	1.16	Negl.	Negl.	Negl.
81A	Eastern California	–	–	–	–	–	–	–	–	–
Region 3--Colorado Plateau and Basin and Range										
082	Eastern Basin and Range	0.09	0.65	0.29	0.03	0.47	0.17	Negl.	0.01	Negl.
083	Western Basin and Range	Negl.	.06	.02	Negl.	.14	.04	Negl.	Negl.	Negl.
084	Idaho-Snake River	.00	.00	.00	.01	.10	.04	0.00	.00	0.00
085	Paradox basin	.01	.72	.20	.04	1.26	.38	Negl.	.01	Negl.
086	Uinta-Piceance basin	.04	.55	.20	1.11	3.76	2.19	.01	.03	.02
087	Park basins	Negl.	.03	.01	.01	.05	.02	.00	.00	.00
088	San Juan basin	.04	.16	.09	1.40	2.73	2.00	Negl.	Negl.	Negl.
089	Albuquerque-Santa Fe rift	Negl.	.07	.02	.06	.63	.25	.00	.00	.00
090	Wyoming thrust belt	.21	1.19	.58	6.29	31.31	15.81	.20	1.34	.61
091	Northern Arizona	.02	.27	.10	.01	.07	.03	.00	.00	.00
092	South Central New Mexico	Negl.	.05	.02	.05	.70	0.26	.00	.00	.00
093	Southern Arizona-Southwestern New Mexico	Negl.	.02	.01	.02	.23	.09	.00	.00	.00
Region 4--Rocky Mountains and Northern Great Plains										
094	Williston basin	0.49	1.15	0.78	0.49	1.07	0.74	0.03	0.06	0.04
095	Sioux Arch (incl. in 094)									
096	Sweetgrass Arch	.05	.18	.10	.31	.95	.57	Negl.	Negl.	Negl.
097	Central Montana	.01	.06	.03	.01	.02	.01	.00	0.00	.00
098	Montana overthrust	Negl.	.04	.01	.42	8.72	2.92	.01	0.19	.07
099	Southwestern Montana	Negl.	.06	.02	.07	1.07	.38	Negl.	0.02	.01
100	Wind River basin	.09	.37	.20	.82	3.55	1.89	.01	0.02	.01
101	Powder River basin	1.16	3.82	2.25	1.38	4.78	2.76	.03	0.12	.06
102	Southwestern Wyoming	.06	.47	.21	1.32	6.76	3.38	.02	0.09	.05
103	Bighorn basin	.10	.49	.25	.18	1.59	.66	Negl.	0.02	.01
104	Denver basin	.37	.87	.59	.96	2.76	1.71	.04	0.08	.06
105	Las Animas Arch	.02	.07	.04	.04	.15	.09	.00	0.00	.00
106	Raton-Sierra Grande	Negl.	.02	.01	.02	.36	.13	Negl.	Negl.	Negl.

Table A1. Estimates of undiscovered recoverable conventional oil, gas, and natural gas liquids (NGL) in onshore provinces and adjacent State waters of the United States—Continued

		Crude oil (billion barrels)			Gas (trillion cubic feet)			NGL (billion barrels)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
Region 5--West Texas and Eastern New Mexico										
107	Permian basin	0.99	3.18	1.89	10.17	28.11	17.74	0.25	0.75	0.46
108	Palo Duro basin	.05	.24	.13	.02	.11	.05	.00	Negl.	Negl.
109	Pedernal uplift	-	-	-	-	-	-	-	-	-
110	Bend Arch-Ft. Worth basin	.37	.76	.54	1.00	2.31	1.57	.05	.10	.07
111	Marathon fold belt	.00	.00	.00	.28	1.63	.78	Negl.	.01	Negl.
Region 6--Gulf Coast										
112	Western Gulf basin	1.59	5.16	3.05	38.71	99.79	64.78	1.02	2.78	1.76
113	East Texas basin	.18	.80	.42	1.51	4.59	2.78	.06	.18	.11
114	La.-Miss. Salt basins	.48	1.16	.77	8.06	24.59	14.91	.57	1.80	1.07
Region 7--Mid-Continent										
115	Anadarko basin	0.49	1.53	0.92	13.77	41.04	25.12	0.33	0.90	0.57
116	Arkoma basin	Negl.	.07	.03	1.01	3.24	1.93	.00	.00	.00
117	Central Kansas uplift	.23	.46	.34	.08	.17	.12	Negl.	Negl.	Negl.
118	Cherokee platform	.18	.37	.27	.36	.74	.53	.01	.02	.01
119	Forest City basin	Negl.	Negl.	Negl.	.01	.02	.01	.00	.00	.00
120	Nemaha uplift	.07	.18	.12	.12	.28	.19	Negl.	.01	Negl.
121	Salina basin	.01	.02	.02	Negl.	.01	Negl.	.00	Negl.	Negl.
122	Sedgwick basin	.06	.11	.08	.32	.66	.47	.01	.01	.01
123	Southern Oklahoma	.05	.21	.11	.15	.52	.30	.01	.02	.01
124	Sioux uplift (incl. in 125)									
125	Iowa Shelf	.00	.00	.00	.00	.31	.06	.00	Negl.	Negl.
126	Ozark uplift	.00	.00	.00	.00	.00	.00	.00	.00	.00
Region 8--Eastern Interior										
127	Michigan basin	0.63	1.62	1.05	3.92	13.40	7.78	0.10	0.30	0.19
128	Illinois basin	.30	.67	.46	.16	1.63	.66	.01	.02	.01
129	Cincinnati Arch	.05	.18	.10	.07	.22	.13	Negl.	Negl.	Negl.
130	Black Warrior basin	Negl.	.01	.01	.73	1.98	1.26	Negl.	.01	.01
131	Appalachian basin	.08	.25	.15	2.77	12.29	6.46	.07	.31	.16
132	Blue Ridge overthrust	.00	.00	.00	.22	1.93	.81	.00	.00	.00
133	Piedmont	.01	.09	.04	.05	.27	.13	.00	.00	.00
134	New England-Adirondack (incl. in 132)									
Region 9--Atlantic Coast										
135	Atlantic Coastal Plain (incl. in 133)									
136	Southern Florida	0.06	0.50	0.21	0.01	0.04	0.02	0.00	0.00	0.00

Table A2. Estimates of undiscovered recoverable oil and gas in Federal offshore provinces of the United States

[Mean value totals may not be equal to the sums of the component means given elsewhere because numbers have been independently rounded. Fractile values (F_{95}, F_5) are not additive. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity. F_{95} represents a 19 in 20 chance and F_5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated]

		Crude oil (billion barrels)			Gas (trillion cubic feet)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean
Region 1A--Alaska							
1	Beaufort Shelf	0.49	3.74	1.27	2.14	12.81	8.26
2	Beaufort basin	Negl.					
3	Chukchi Sea	.00	7.19	2.22	.00	16.87	6.33
4	Chukchi Borderland	Negl.					
5	Hope basin	.00	.04	.02	.00	.94	.26
6	Norton basin	.00	.05	.01	.00	1.79	.19
7	St. Matthew-Hall	Negl.					
8	Navarin basin	.00	.12	.07	.00	.10*	.23
9	St. George basin	.00	.05	.03	.00	1.46	.37
10	Northern Aleutian basin	.00	.02*	.03	.00	.70	.16
11	Bering basin	Negl.					
12	Aleutian Arc	Negl.					
13	Aleutian Trench	Negl.					
14	Shumagin Shelf	.00	.00	.01	.00	.00	.04
15	Cook Inlet	.00	.30	.03	.00	.67	.05
16	Kodiak Shelf	.00	.18	.04	.00	.39	.20
17	Gulf of Alaska Shelf	.00	1.39	.12	.00	4.59	.67
18	Gulf of Alaska basin	Negl.					
Region 2A--Pacific Coast							
19	Oregon-Washington	0.00	0.24	0.06	0.00	2.57	0.57
20	Northern California-Southern Oregon	.00	.40	.13	.00	5.04	1.61
21	Central California	.68	2.45	1.55	.83	3.63	1.93
22	Santa Maria	.10	1.03	.59	.08	.71	.54
23	Santa Barbara-Ventura	.18	.49	.32	.48	1.35	.90
24	Los Angeles basin	.00	.42	.09	.00	.73	.13
25	Inner Banks	.07	.83	.45	.06	1.84	.78
26	Outer Banks	.00	.89	.33	.00	4.40	1.55
Region 6A--Gulf of Mexico							
27	Cenozoic	5.07	14.60	9.27	58.36	154.91	100.34
28	Mesozoic	.12	.52	.30	.55	7.84	3.00
Region 9A--Atlantic Coast							
29	Gulf of Maine	0.00	0.00	Negl.	0.00	0.00	0.02
30	Georges Bank	.00	.38	.10	.00	6.75	1.94
31	Baltimore Canyon	.05	1.16	.48	1.34	22.46	9.72
32	Carolina Trough	.00	.71	.20	.00	13.37	3.57
33	Southeastern Georgia Embayment	.00	.00	Negl.	.00	.00	.02
34	Blake Plateau	.00	.56	.08	.00	7.66	1.38
35	Florida Straits	.00	.45	.08	.00	1.86	.38

* In these cases, the low marginal probability causes the risked mean to be located at a percentile below the 5th percentile, so the result is that the risked mean is greater than the risked 5 percent estimate.

Table A3. Estimates of undiscovered economically recoverable conventional oil, gas, and natural gas liquids (NGL) in onshore provinces and adjacent State waters of the United States

[Mean value totals may not be equal to the sums of the component means given elsewhere because numbers have been independently rounded. Fractile values (F_{95}, F_5) are not additive. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity. F_{95} represents a 19 in 20 chance and F_5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated]

		Crude oil (billion barrels)			Gas (trillion cubic feet)			NGL (billion barrels)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
Region 1--Alaska										
058	Arctic Coastal Plain	0.00	10.93	3.36	0.00	0.00	0.00	0.00	0.00	0.00
059	Northern Foothills	.00	2.64	.72	.00	.00	.00	.00	.00	.00
060	Southern Foothills	.00	12.64	3.59	.00	.00	.00	.00	.00	.00
061	Kandik	.00	.00	.00	.00	.00	.00	.00	.00	.00
062	Alaska Interior	.00	.00	.00	.00	.00	.00	.00	.00	.00
063	Interior Lowlands (incl. in 062)									
064	Bristol basin	.00	.00	.00	.00	.00	.00	.00	.00	.00
065	Hope basin	.00	.00	.00	.00	.00	.00	.00	.00	.00
066	Copper River (incl. in 062)									
067	Cook Inlet	.05	.60	.24	.15	3.69	1.20	.00	Negl.	Negl.
068	Alaska Peninsula (incl. in 062)									
069	Gulf of Alaska	.00	.00	.00	.00	.00	.00	.00	.00	.00
070	Kodiak	.00	.00	.00	.00	.00	.00	.00	.00	.00
071	Southeastern Alaska	.00	.00	.00	.00	.00	.00	.00	.00	.00
Region 2--Pacific Coast										
072	Western Oregon-Washington	0.00	0.00	0.00	0.80	4.28	2.06	0.00	0.00	0.00
073	Sacramento basin	.00	.00	.00	.72	3.25	1.70	Negl.	Negl.	Negl.
074	San Joaquin basin	.55	3.21	1.53	1.22	6.68	3.26	.08	.53	.24
075	Los Angeles basin	.20	1.50	.66	.25	1.60	.78	.01	.08	.04
076	Ventura basin	.16	1.65	.66	.34	2.80	1.21	.01	.12	.05
077	Santa Maria basin	.11	.50	.26	.10	.43	.23	.01	.02	.01
078	Central Coastal	.05	.71	.26	.04	.57	.21	Negl.	.02	.01
079	Sonoma-Livermore basin	.00	.01	Negl.	.00	.01	Negl.	.00	.00	.00
080	Humboldt basin	.00	.00	.00	Negl.	.08	.02	.00	.00	.00
081	Eastern Oregon-Washington	.00	.00	.00	.41	2.32	1.12	.00	Negl.	Negl.
081A	Eastern California	.00	.00	.00	.00	.00	.00	.00	.00	.00
Region 3--Colorado Plateau and Basin and Range										
082	Eastern Basin and Range	0.08	0.62	0.26	0.03	0.44	0.16	0.00	0.01	Negl.
083	Western Basin and Range	Negl.	.04	.01	Negl.	.13	.04	.00	Negl.	Negl.
084	Idaho-Snake River	.00	.00	.00	.00	.10	.03	.00	.00	.00
085	Paradox basin	.01	.68	.18	.03	1.20	.35	Negl.	.01	Negl.
086	Uinta Piceance basin	.03	.54	.19	1.08	3.70	2.15	.01	.03	.02
087	Park basins	Negl.	.03	.01	.01	.05	.02	.00	.00	.00
088	San Juan basin	.04	.15	.08	1.39	2.70	1.97	.00	Negl.	Negl.
089	Albuquerque-Santa Fe rift	Negl.	.07	.02	.05	.59	.22	.00	.00	.00
090	Wyoming thrust belt	.21	1.17	.56	6.22	31.15	15.70	.20	1.33	.61
091	Northern Arizona	.02	.27	.10	.01	.07	.03	.00	.00	.00
092	South Central New Mexico	Negl.	.05	.02	.05	.67	.24	.00	.00	.00
093	Southern Arizona-Southwestern New Mexico	Negl.	.01	.01	.02	.21	.08	.00	.00	.00
Region 4--Rocky Mountains and Northern Great Plains										
094	Williston basin	0.29	0.80	0.51	0.33	0.78	0.52	0.02	0.04	0.03
095	Sioux Arch (incl. in 094)									
096	Sweetgrass Arch	.04	.17	.09	.30	.93	.56	Negl.	Negl.	Negl.
097	Central Montana	.01	.06	.03	.01	.02	.01	.00	.00	.00
098	Montana overthrust	Negl.	.04	.01	.41	8.65	2.89	.01	.19	.07
099	Southwestern Montana	Negl.	.05	.01	.06	1.04	.36	Negl.	.02	.01
100	Wind River basin	.09	.36	.19	.79	3.49	1.84	.01	.02	.01
101	Powder River basin	1.02	3.55	2.04	1.21	4.45	2.51	.03	.12	.06
102	Southwestern Wyoming	.06	.46	.20	1.19	6.51	3.19	.02	.08	.04
103	Bighorn basin	.09	.47	.24	.17	1.55	.64	Negl.	.02	.01
104	Denver basin	.26	.67	.43	.77	2.44	1.46	.03	.06	.04
105	Las Animas Arch	.02	.06	.03	.04	.15	.08	.00	.00	.00
106	Raton-Sierra Grande	Negl.	.02	.01	.02	.34	.12	Negl.	Negl.	Negl.

Table A3. Estimates of undiscovered economically recoverable conventional oil, gas, and natural gas liquids (NGL) in onshore provinces and adjacent State waters of the United States—Continued

	Crude oil (billion barrels)			Gas (trillion cubic feet)			NGL (billion barrels)		
	F_{95}	F_5	Mean	F_{95}	F_5	Mean	F_{95}	F_5	Mean
Region 5--West Texas and Eastern New Mexico									
107 Permian basin	0.94	3.11	1.82	9.68	27.32	17.09	0.24	0.73	0.44
108 Palo Duro basin	.05	.23	.12	.02	.10	.05	Negl.	Negl.	Negl.
109 Pedernal uplift	.00	.00	.00	.00	.00	.00	.00	.00	.00
110 Bend Arch	.30	.63	.44	.91	2.14	1.44	.04	.10	.06
111 Marathon fold belt	.00	.00	.00	.26	1.58	.74	Negl.	.01	Negl.
Region 6--Gulf Coast									
112 Western Gulf basin	1.51	5.14	2.99	36.30	97.84	62.36	0.96	2.74	1.71
113 East Texas basin	.17	.77	.40	1.34	4.29	2.55	.05	.16	.10
114 La.-Miss. Salt basins	.36	.96	.62	7.09	23.90	14.41	.49	1.70	1.05
Region 7--Mid-Continent									
115 Anadarko basin	0.44	1.38	0.83	12.71	38.49	23.41	0.30	0.84	0.53
116 Arkoma basin	Negl.	.07	.02	.90	3.05	1.77	.00	.00	.00
117 Central Kansas uplift	.23	.46	.34	.08	.17	.12	Negl.	Negl.	Negl.
118 Cherokee platform	.18	.37	.26	.36	.73	.53	.01	.02	.01
119 Forest City basin	Negl.	Negl.	Negl.	.01	.02	.01	.00	.00	.00
120 Nemaha uplift	.07	.18	.11	.12	.27	.19	Negl.	.01	Negl.
121 Salina basin	.01	.02	.01	Negl.	.01	Negl.	.00	.00	.00
122 Sedgwick basin	.05	.10	.08	.31	.64	.46	.01	.01	.01
123 Southern Oklahoma	.04	.17	.09	.11	.45	.24	Negl.	.02	.01
124 Sioux Uplift (incl. in 125)									
125 Iowa Shelf	.00	.00	.00	.00	.22	.05	.00	Negl.	Negl.
126 Ozark uplift	.00	.00	.00	.00	.00	.00	.00	.00	.00
Region 8--Eastern Interior									
127 Michigan basin	0.61	1.59	1.03	3.70	13.03	7.47	0.10	0.29	0.18
128 Illinois basin	.30	.67	.46	.16	1.63	.66	.01	.02	.01
129 Cincinnati Arch	.05	.18	.10	.07	.22	.13	Negl.	Negl.	Negl.
130 Black Warrior basin	Negl.	.01	.01	.68	1.90	1.19	Negl.	.01	.01
131 Appalachian basin	.07	.22	.13	2.55	11.44	5.99	.07	.28	.15
132 Blue Ridge overthrust	.00	.00	.00	.18	1.93	.76	.00	.00	.00
133 Piedmont	.01	.08	.04	.04	.23	.11	.00	.00	.00
134 New England-Adirondack (incl. in 132)									
Region 9--Atlantic Coast									
135 Atlantic Coastal Plain (incl. in 133)									
136 Southern Florida	0.05	0.50	0.21	Negl.	0.04	0.02	0.00	0.00	0.00

Table A4. Estimates of undiscovered economically recoverable oil and gas in Federal offshore provinces of the United States

[Mean value totals may not be equal to the sums of the component means because numbers have been independently rounded. Fractile values (F_{95}-F_5) are not additive. Gas includes both nonassociated and associated-dissolved gas. Negl., negligible quantity. F_{95} represents a 19 in 20 chance and F_5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated]

		Crude oil (billion barrels)			Gas (trillion cubic feet)		
		F_{95}	F_5	Mean	F_{95}	F_5	Mean
Region 1A--Alaska							
1	Beaufort Shelf	0.00	1.74	0.21	0.00	0.00	0.00
2	Beaufort basin	Negl.					
3	Chukchi Sea	.00	3.59	.59	.00	.00	.00
4	Chukchi Borderland	Negl.					
5	Hope basin	.00	.00	Negl.	.00	.00	.00
6	Norton basin	.00	.00	Negl.	.00	.00	.00
7	St. Matthew-Hall	Negl.					
8	Navarin basin	.00	.00	.03	.00	.00	.00
9	St. George basin	.00	.00	.01	.00	.00	.00
10	Northern Aleutian basin	.00	.00	.01	.00	.00	.00
11	Bering basin	Negl.					
12	Aleutian Arc	Negl.					
13	Aleutian Trench	Negl.					
14	Shumagin Shelf	.00	.00	Negl.	.00	.00	.00
15	Cook Inlet	.00	.00	Negl.	.00	.00	.00
16	Kodiak Shelf	.00	.00	.02	.00	.00	.00
17	Gulf of Alaska Shelf	.00	.00	.03	.00	.00	.00
18	Gulf of Alaska basin	Negl.					
Region 2A--Pacific Coast							
19	Oregon-Washington	0.00	0.23	.04	.00	2.44	0.46
20	Northern California-Southern Oregon	.00	.14	.04	.00	2.42	.69
21	Central California	.13	1.33	.74	.21	1.80	1.05
22	Santa Maria	.02	.61	.26	.02	.53	.25
23	Santa Barbara-Ventura	.13	.48	.29	.41	1.25	.79
24	Los Angeles basin	.00	.43	.09	.00	.76	.13
25	Inner Banks	.04	.82	.40	.05	1.52	.69
26	Outer Banks	.00	.90	.23	.00	4.22	1.11
Region 6A--Gulf of Mexico							
27	Cenozoic	2.24	9.04	5.36	28.24	102.33	62.10
28	Mesozoic	.05	.58	.27	.01	6.77	2.22
Region 9A--Atlantic Coast							
29	Gulf of Maine	0.00	0.00	Negl.	0.00	0.00	0.02
30	Georges Bank	.00	.19	.04	.00	4.16	.98
31	Baltimore Canyon	.00	.40	.10	.00	9.44	2.36
32	Carolina Trough	.00	.21	.03	.00	5.02	.77
33	Southeastern Georgia Embayment	Negl.					
34	Blake Plateau	.00	.16	.02	.00	2.51	.30
35	Florida Straits	.00	.42	.06	.00	.54	.08

APPENDIX B: CONDITIONAL RESOURCE ESTIMATES FOR THE FEDERAL OFFSHORE

Distributions of risked undiscovered resources incorporate the risk that hydrocarbons may not exist in an area. In mature exploration areas, such as the onshore United States and the Gulf of Mexico offshore, this risk is absent. However, in some regions of the Federal offshore, this risk can be considerable, particularly in frontier exploration areas. Conditional resource distributions (tables B1 and B2) remove this risk by assuming that hydrocarbons do exist in the area. The marginal probability (MPhc) indicates the chance that recoverable volumes of hydrocarbons actually exist in the area.

The estimates presented previously in this document are risked. Risked estimates are appropriate for comparisons, because by incorporating risk, all areas are placed on a common basis. Conditional estimates are not directly comparable because they are based on different conditions, as represented by the different marginal probabilities. However, if oil and gas do exist in the area, the amounts could be quite large. The conditional estimate is the appropriate indicator to consider when assessing the impact of development in an area if hydrocarbons are discovered.

Conditional distributions are presented in this appendix only for the Federal offshore, where the difference between conditional and risked distributions is most significant.

Table B1. Conditional estimates of undiscovered conventionally recoverable petroleum resources for Federal offshore provinces

[Mean value totals may not be equal to the sums of the component means because numbers have been independently rounded. Fractile values (F_5, F_{95}) are not additive. Gas includes both nonassociated and associated-dissolved gas. MPhc, marginal probability; Negl., negligible quantity; BB, billion barrels; TCF, trillion cubic feet]

Province	Conditional oil (BB)			Conditional Gas (TCF)			
	95% case	5% case	Mean case	95% case	5% case	Mean case	MPhc
ALASKA:							
Beaufort Shelf	0.49	3.74	1.27	2.14	12.81	8.26	1.00
Beaufort basin	Negl.						
Chukchi Sea	1.27	8.25	4.44	6.73	17.83	12.66	.50
Chukchi Borderland	Negl.						
Hope basin	.06	.44	.32	2.13	13.08	5.22	.05
Norton basin	.04	.88	.19	1.25	3.57	2.70	.07
St. Matthew-Hall	Negl.						
Navarin basin	.07	5.29	1.33	1.74	2.64	4.62	.05
St. George basin	.12	1.03	.59	3.98	12.47	7.41	.05
Northern Aleutian basin	.17	.85	.52	.48	10.09	3.12	.05
Bering basin	Negl.						
Aleutian Arc	Negl.						
Aleutian Trench	Negl.						
Shumagin Shelf	.11	.81	.40	1.44	2.15	1.96	.02
Cook Inlet	.08	.52	.32	.04	.89	.47	.10
Kodiak Shelf	.11	.88	.81	3.04	9.32	3.92	.05
Gulf of Alaska Shelf	.33	1.62	1.17	3.18	15.03	6.70	.10
Gulf of Alaska basin	Negl.						
Total Alaska	.59	11.21	3.84	4.67	39.42	16.75	1.00
ATLANTIC:							
Georges Bank	0.04	0.41	0.21	1.05	7.75	3.88	0.50
Gulf of Maine	.02	.06	.04	.45	1.78	1.02	.02
Baltimore Canyon	.05	1.16	.48	1.34	22.46	9.72	1.00
Blake Plateau	.02	.49	.34	.50	13.36	5.56	.25
Carolina Trough	.07	.69	.37	.69	16.25	6.49	.55
Southeastern Georgia Embayment	.03	.07	.05	.44	.97	.67	.03
Florida Straits	.04	.62	.26	.30	2.52	1.20	.32
Total Atlantic	.09	3.15	.96	6.78	33.71	17.03	1.00
GULF OF MEXICO:							
Cenozoic	5.07	14.60	9.27	58.36	154.91	100.34	1.00
Mesozoic	.12	.52	.30	.55	7.84	3.00	1.00
Total Gulf of Mexico	5.52	15.12	9.57	63.02	156.92	103.34	1.00
PACIFIC:							
Oregon-Washington	0.16	0.27	0.22	1.71	2.87	2.28	0.25
N. Calif.-S. Oreg.	.28	.44	.36	3.66	5.26	4.47	.36
Central California	1.09	2.56	1.63	1.42	3.10	2.03	.95
Santa Maria	.34	1.02	.62	.19	.85	.57	.95
Santa Barbara-Ventura	.18	.49	.32	.48	1.35	.90	1.00
Inner Banks	.15	.81	.47	.37	2.08	.82	.95
Los Angeles basin	.06	.47	.12	.06	.82	.17	.76
Outer Banks	.39	.96	.66	1.90	4.89	3.10	.50
Total Pacific	.81	8.92	3.51	3.50	15.07	8.01	1.00
Total Federal Offshore	9.76	29.29	17.88	97.76	204.81	145.12	1.00

Table B2. Conditional estimates of undiscovered economically recoverable petroleum resources for Federal offshore provinces

[Mean value totals may not be equal to the sums of the component means because numbers have been independently rounded. Fractile values (F_5, F_{95}) are not additive. Gas includes both nonassociated and associated-dissolved gas. MPhc, marginal probability; Negl., negligible quantity; N/A, not available because of an insufficient number of data points; BB, billion barrels; TCF, trillion cubic feet]

Province	Conditional oil (BB)			Conditional Gas (TCF)			
	95% case	5% case	Mean case	95% case	5% case	Mean case	MPhc
ALASKA:							
Beaufort Shelf	0.55	4.02	1.44	0.00	0.00	0.00	0.14
Beaufort basin	Negl.						
Chukchi Sea	1.03	5.41	2.73	.00	.00	.00	.22
Chukchi Borderland	Negl.						
Hope basin	.20	1.96	.66	.00	.00	.00	.01
Norton basin	N/A	N/A	.58	.00	.00	.00	<.01
St. Matthew-Hall	Negl.						
Navarin basin	.17	4.95	1.14	.00	.00	.00	.03
St. George basin	.17	.91	.39	.00	.00	.00	.02
Northern Aleutian basin	.17	2.08	.61	.00	.00	.00	.02
Bering basin	Negl.						
Aleutian Arc	Negl.						
Aleutian Trench	Negl.						
Shumagin Shelf	.12	.57	.28	.00	.00	.00	.01
Cook Inlet	.14	.26	.17	.00	.00	.00	<.01
Kodiak Shelf	.13	1.23	.53	.00	.00	.00	.04
Gulf of Alaska Shelf	.17	2.12	.87	.00	.00	.00	.04
Gulf of Alaska basin	Negl.						
Total Alaska	1.10	7.24	3.32	.00	.00	.00	.28
ATLANTIC:							
Georges Bank	0.05	0.27	0.11	1.12	5.31	2.51	0.39
Gulf of Maine	.02	.07	.04	.62	1.81	1.09	.02
Baltimore Canyon	.07	.47	.22	2.36	11.46	5.35	.44
Blake Plateau	.11	.57	.31	1.72	8.40	4.67	.06
Carolina Trough	.07	.33	.15	1.61	7.76	3.53	.22
Southeastern Georgia Embayment	Not Economic						
Florida Straits	.18	.68	.35	.21	.79	.44	.18
Total Atlantic	.02	1.17	.32	2.63	10.22	5.65	.80
GULF OF MEXICO:							
Cenozoic	2.24	9.04	5.36	28.24	102.33	62.10	1.00
Mesozoic	.10	.58	.28	.01	6.84	2.32	.96
Total Gulf of Mexico	2.77	9.88	5.64	36.01	103.65	64.33	1.00
PACIFIC:							
Oregon-Washington	0.06	0.28	0.18	0.67	2.96	1.84	0.25
N. Calif.-S. Oreg.	.07	.16	.11	1.24	2.78	1.92	.36
Central California	.31	1.34	.77	.51	1.82	1.10	.95
Santa Maria	.05	.62	.27	.06	.54	.26	.95
Santa Barbara-Ventura	.13	.48	.29	.41	1.25	.79	1.00
Inner Banks	.12	.83	.42	.17	1.55	.72	.95
Los Angeles basin	.01	.49	.13	.01	.88	.18	.72
Outer Banks	.12	1.04	.50	.58	4.80	2.39	.47
Total Pacific	.34	6.02	2.10	1.78	11.04	5.17	1.00
Total Federal Offshore	4.24	15.93	8.91	44.31	113.84	74.00	1.00

*U.S. G.P.O. 1989-242-338:80069